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DRYING ROUGH RICE WITH INFRARED RADIATION

(A reprint of five articles from
the Rice Journal reporting on
Federal and State research work)

U. S. DEPARTMENT OF AGRICULTURE AGRICULTURAL MARKETING SERVICE MARKET QUALITY RESEARCH DIVISION

PREFACE AND SUMMARY

The articles reprinted here from the Rice Journal describe a series of laboratory experiments on the use of a gas-fired infrared heater for drying rough rice. The primary objective of these experiments was to gain information on the effects of this method of moisture removal on rice quality. A multipass system is required, and drying takes place in two distinct steps; during irradiation and during cooling or "tempering."

The amount of moisture removed from the 200-gram samples of rice in exposures to irradiation for 10 to 30 seconds ranged from 0.9 to 2.1 grams. Moisture removal appeared to be directly proportional to the moisture content of the rice at the beginning of the irradiation period. There were significant differences in drying rates among varieties and, in some cases, among lots within varieties.

The amount of moisture lost during cooling or "tempering" was found to equal or exceed that removed during irradiation. This moisture loss during cooling is dependent on temperature and relative humidity of the atmosphere, the degree of exposure of the rice to the air, and other factors.

Yields of head rice (whole grains) and total milling yields equal to or better than corresponding yields from air-dried samples were obtained with proper irradiation treatment. Highest milling yields were obtained with the variety Bluebonnet harvested 9 days prior to what was later determined as normal harvest. Milling yields declined with increased "maturity." High initial moisture content was associated with high milling yields.

In a preliminary study, infrared radiation, within the range acceptable for drying without damage to milling quality, was found to kill immature rice weevils and lesser grain borers. Additional studies on insect control by infrared radiation are under way.

In this series of experiments, no attempt was made either to measure amounts of infrared energy emitted by the heater or to compare the efficiency of the infrared drying system with more commonly used methods of drying rough rice.

The experiments reported were conducted by personnel of the Field Crops and Animal Products Branch of the Market Quality Research Division, Agricultural Marketing Service, in cooperation with personnel of the Texas Agricultural Experiment Station, College Station, Texas.

C. H. Kingsolver
Agricultural Marketing Service

Washington, D.C.

January 1962

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Drying Rough Rice With Infra-Red Radiation

By HARRY W. SCHROEDER and DAVID W. ROSBERG*

Small scale laboratory tests were conducted at College Station, Texas, in August and September 1958 to determine the effects of infra-red radiation from a gas-fired "Schwank" infra-red 48,000 BTU heater on the drying of rough rice.

The experiments were designed to provide information on rates of drying, effects of this type of drying on milling yields and germination and to provide a basis for further experimentation to determine the possibilities for commercial application of the method for drying rice and other agricultural products.

EXPERIMENTAL PROCEDURE:

The rice used in these experiments was obtained from the Rice-Pasture Experiment Station at Beaumont. This experimental long-grain selection used is of very early maturity and has a low milling yield. The rice was harvested late in July at a moisture content of 24 to 25 per cent and was transported immediately to College Station where it was stored in sealed containers, refrigerated at 45° F. until used in the drying experiments.

The basic procedures in the three experiments in this report were: (1) a quantity of green rice was mixed thoroughly; (2) split into samples of approximately 1 pint by volume with a Boerner Sampler; (3) the moisture content was determined for each sample; (4) the sample was sealed in pint mason jars until exposed to infra-red radiation; (5) the rice was spread on screen-bottomed trays in an approximately single kernel layer for drying; (6) when a laboratory thermometer at the level of the rice reached a pre-determined temperature, the tray was removed from beneath the heater and the exposure time recorded; (7) intensity of radiation was varied by increasing or decreasing the distance between the rice and the heater; and (8) all moisture determinations were made with a CAE (Motomco) Moisture Meter.

In experiment 1, the trays were placed in front of a fan after irradiation until the rice cooled to room temperature and a moisture content determination was made. This procedure was repeated until the moisture content was reduced to approximately 14 per cent. The samples were then sealed in their original containers and stored until they were milled.

Experiment 2 duplicated the treatments of experiment 1 except that immediately after irradiation the samples were returned to their containers and allowed to stand at room temperature with tops removed for approximately 10 hours before a moisture determination was made. The containers were then sealed until the entire process could be repeated. In effect, there was a 24-hour or longer tempering period between exposures. The samples dried in experiment 2 were placed on screen-bottomed trays at room temperature for 4 days prior to milling. This was done in an attempt to bring all samples to the same moisture content so that any noted effects on head yield could be attributed to the infra-red drying treatments.

Experiment 3 was conducted with methods similar to those described for experiment 2. A different range of maximum temperatures and radiation intensities were used and the samples were not air-dried after the last exposure to infra-red.

All treatments were replicated three times.

Control samples were air-dried at room temperature on screened trays; otherwise they were treated in an identical manner as the infra-red dried samples.

Milled yields are based on 125 gram samples of rough rice, milled with a modified portable McGill Miller using two breaks at 15 and 5 pounds pressure, respectively, for 30 seconds each break.

RESULTS:

The data compiled for experiments 1 and 2 are compared in Tables 1 and 2. Tempering between exposures

TABLE 1. Comparison of treatments and their effects on moisture removal in Experiment 1 (non-tempered) and Experiment 2 (tempered)

Maximum temperature of rice, °C			50			55			60	
Distance from heater, inches		14	22	30	14	22	30	14	22	30
Number of exposures to infra-red	Non-temp.	10	10	10	7	7	8	6	7	8
	Tempered	5	5	5	5	5	5	5	5	5
Total exposure to infra-red, minutes	Non-temp.	3.93	8.63	14.05	3.93	7.35	12.63	4.37	9.42	19.30
	Tempered	2.42	4.42	8.15	3.38	6.45	12.78	3.98	8.43	17.69
Per cent moisture removed during total exposure	Non-temp.	9.70	9.10	9.10	9.80	9.30	9.80	9.40	9.60	9.50
	Tempered	8.70	9.10	9.90	10.30	10.70	10.90	11.20	11.60	12.00
Per cent moisture removed per mintue of exposure	Non-temp.	2.47	1.24	.72	2.49	1.08	.70	2.15	1.04	.49
	Tempered	3.60	2.06	1.21	3.05	1.66	.85	2.81	1.38	.68

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appears to have increased the efficiency of moisture removal. As temperature was increased and radiation intensity decreased, this effect of tempering on the rate of moisture removal was not as great (Table 1).

The most efficient moisture removal was obtained at the lowest temperature, 50°C., but at the highest radiation intensity, 14 inches from the heater. Radiation intensity appear to have a greater effect on removing moisture from rough rice than does the actual temperature to which the rice is heated; therefore, the faster the temperature of rice is raised the faster moisture is removed.

Heating the rice to 50°C. at high radiation intensity appears to be the most efficient treatment; however, the total moisture removed was not equal for all treatments since moisture removal is progressively slower as the rice becomes drier, Table 1. Further experimentation is necessary before the most efficient treatment can be ascertained.

The milling yields, Table 2, suggested that high temperatures and high radiation intensity increase milling yields. The lack of replication and failure to control the final moisture content accurately in these preliminary experiments prevent a close evaluation of the data, but a pattern is apparent in the results, providing a basis for continued work.

Germination tests showed that germination decreases when the rice is dried rapidly at high temperature and the infra-red irradiation exposure period is increased.

Experiment 3 was planned and executed prior to obtaining the milling

FIGURE 1. Rate of drying of rough rice exposed to infra-red radiation at a distance of 10 inches from the heater and heated to 45 degrees Centigrade, compared with the rate of drying at the same intensity but heated to 50 degrees Centigrade.

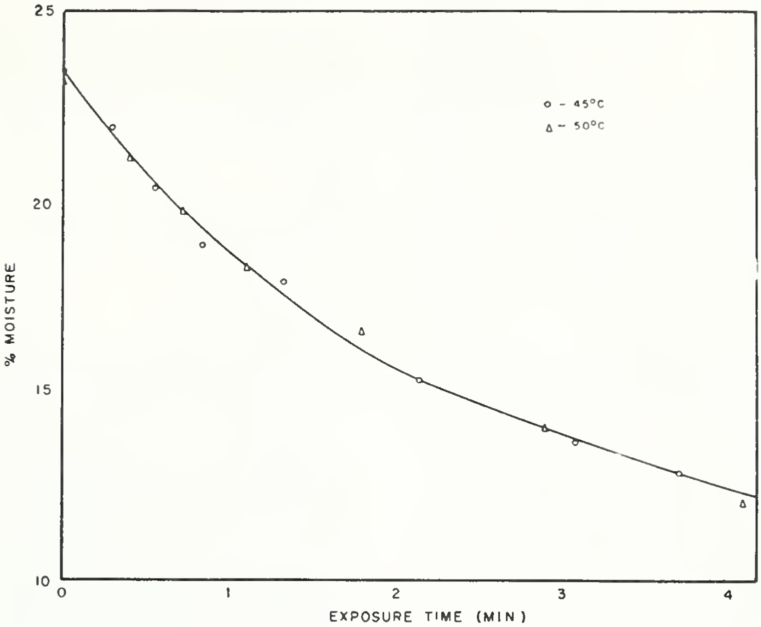


TABLE 2. Comparison of the effects of treatments on quality as measured by yield of head rice and germination between Experiment 1 (non-tempered) and Experiment 2 (tempered)

Maximum temperature of rice, °C				50			55			60		
Distance from heater, inches			14	22	30	14	22	30	13	22	30	Control[1]
Moisture content	Non-temp.		14.7	14.6	14.3	15.3	14.9	14.3	15.2	14.9	14.7	13.7
when milled, %	Tempered		12.7	11.8	11.3	12.2	12.0	11.3	12.3	12.0	11.0	11.3
Head rice in % of	Non-temp.		90.5	88.8	94.5	99.1	94.5	93.8	116.8	111.5	100.7	100.0
control, dry basis	Tempered		89.5	92.6	89.2	92.5	93.7	98.3	114.4	94.2	85.5	100.0
Per cent germina-	Non-temp.	10	64	65	0	7	7	20	1	0	25	50
tion	Tempered		51	84	91	3	46	84	0	8	53	90

[1] Air-dried at room temperature.

TABLE 3. Results of drying rough rice with infra-red radiation at three radiation intensity levels and heating to 2 maximum temperatures[1]

Maximum temperature of rice, °C		45			50		
Distance from heater, inches	10	14	18	10	14	18	Control[2]
Number of exposures to infra-red	15	15	15	13	13	13	0
Total exposure to infra-red, minutes	3.60	4.80	6.20	4.10	5.60	7.30	0
Per cent moisture removed during total exposure	10.60	11.00	10.90	11.40	11.60	12.00	2.90[3]
Per cent moisture removed per minute of exposure	2 .94	2.29	1.76	2.78	2.07	1.64	
Moisture content when milled	13.70	13.50	13.30	11.50	11.90	11.40	13.40
Total yield milled in % of control, dry basis	101.60	100.10	100.90	103.50	102.70	104.70	100.00
Yield head rice in % of control, dry basis	94.00	94.30	100.90	114.50	122.00	123.20	100.00
Per cent germination	39	69	82	5	26	65	72

[1] Average of three replications.

[2] Air-dried at room temperature.

[3] Moisture lost from open containers during the cooling period at room temperature.

yields from experiments 1 and 2. The data in Table 3 are an average of three replications. The rate of moisture removal per minute of infra-red exposure followed the same pattern as observed in experiments 1 and 2; that is, increased radiation intensity and lower maximum temperature of the rice apparently increase the rate of moisture removal. To minimize the effects of final moisture content on the rate of moisture, the data are plotted in Figure 1 for rice dried at both temperatures at radiation intensity obtained 10 inches from the heater. The difference between drying rates is not significant. The data in Table 3 show a significant difference between drying rates when radiation intensity is decreased; hence the temperature to which the rice is heated apparently does not influence the rate of drying as much as does the intensity of the radiation.

It, therefore, is assumed that rapid drying was achieved as a direct effect of infra-red radiation and not as a result of merely raising the temperature of the rice.

The head yield of infra-red-dried rice was increased over the head yield of the air-dried (room temperature) control in four of the six treatments in this experiment. Head yield tended to increase inversely with the rate of moisture removal following the trend observtd in experiments 1 and 2. An analysis of variance of head yield in grams, disregarding the moisture content at the time of milling, is given in Table 4.

TABLE 4. Analysis af variance of head yield in Experiment 3, disregarding moisture content of rice at time of milling

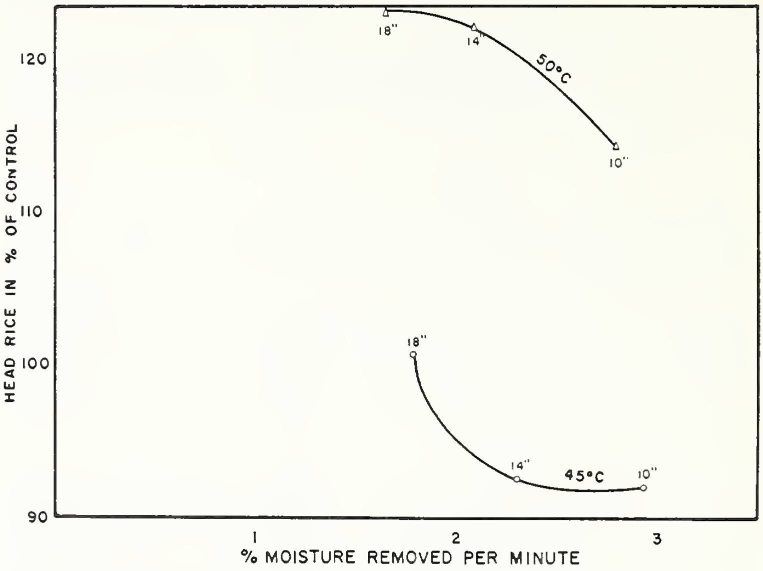
Source of variation	DF	SS	MS	F
Total	20	345.26		
Treatments	6	294.98	49.16	13.69[1]
Error	14	50.28	3.59	

[1]Significant at the 1 per cent level.

Using Duncan's range test of significance of variance of means for the 5 per cent level, yields from all treatments heated to 50°C. were significantly greater than the head yield of the control. There was no significant difference between the control and any of the samples heated to 45°C.

Head yield was plotted in relation to the percentage of moisture removed per minute of exposure (Figure 2). Head yield decreased as the rate of drying increased for both temperatures. Figure 2 also shows that head yield decreases as infra-red radiation intensity increases.

FIGURE 2. The relation of yield of head rice to drying rates for rice heated to maximum temperatures of 45 degrees Centigrade and 50 degrees Centigrade, at distances of 10, 14 and 18 inches from the heater.



SUMMARY

Preliminary experiments with drying rough rice with infra-red radiation from a gas-fired infra-red heater indicate possibilities for developing a faster method of drying rice and other agricultural products than conventional systems now in general use. Drying rates were obtained which ranged from 3.60 to 0.49 per cent moisture removed per minute of exposure to infra-red. Yield of head rice was increased significantly over the yield from control samples air-dried at room temperature.

Rate of drying varied directly with radiation intensity, but was affected little by the maximum temperature to which the rice was heated.

Head yield varied directly with total time rice was exposed to infra-red radiation and with the maximum temperature to which it was heated. It varied inversely with radiation intensity and with increasing rates of moisture removal.

Germination decreased as temperature and rate of moisture removal increased.

ACKNOWLEDGEMENT

These studies were conducted by the Quality Maintenance and Improvement Section, Biological Sciences Branch, Marketing Research Division, Agricultural Marketing Service, United States Department of Agriculture, and the Texas Agricultural Experiment Station in cooperation with the Texas Infra Red Company, Houston, Texas.

INFRA-RED DRYING OF ROUGH RICE

I. Long-Grain Type

Rexoro and Bluebonnet 50

By

Harry W. Schroeder and David W. Rosberg[1]

SUMMARY

Two varieties of long-grained rough rice, Rexoro and Bluebonnet 50, were exposed to varying amounts of infra-red radiation at three and four moisture-content levels, respectively.

The energy input was 4,766 B.t.u. per hour per square foot of irradiated surface, calculated on the basis of the rated input of the heater. Two hundred grams of rice per square foot were irradiated in each of the replicated treatments.

The rate of drying, for both varieties, decreased as the initial moisture content of the rice was decreased, and increased as the irradiation period was lengthened from 10 seconds to 25 seconds. The drying rates for the irradiation periods varied from 1.2 to 1.7 grams water removed from 200 g. rough rice per 10 seconds of irradiation for Rexoro, and from 1.2 to 2.1 grams for Bluebonnet 50.

The mean yield of head rice did not differ significantly from controls air dried at room temperature, in 14 out of 18 treatments for Rexoro and for 14 out of 16 treatments for Bluebonnet 50.

The drying rate for Bluebonnet 50 was more rapid than the drying rate for Rexoro during comparable periods of irradiation.

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Introduction

Infra-red drying differs from the conventional heated-air drying methods in that the object being dried is heated directly by absorption of infra-red radiation rather than by transfer to heat from air which was initially heated by an energy source. Thus, infra-red drying is very similar to natural drying by radiation from the sun. The primary differences between the sun and the source of infra-red used in these experiments are in the range and intensity of the infra-red spectrum.

DR. HARRY W. SCHROEDER

The preliminary studies on the drying of rough rice with infra-red radiation reported in 1959[2], pointed out the need for more basic and detailed information on the influence of moisture content and rate of drying on the milling yield of rice. Differences between grain types and varieties as to rate of drying also appeared probable and needed to be investigated.

The highest radiation intensity available was used to minimize the exposure time although our previous studies had shown that such high intensities did not result in as high milling yields as lower intensities with longer exposures.

Methods and Materials

Samples of rough rice of the varieties Rexoro and Bluebonnet 50 were obtained in the field at harvest. The rice was stored in 5- and 8-gallon cylindrical cans with "friction sealed" lids. The cans were further sealed with a moisture proof adhesive tape and were then placed in a walk-

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[2] Schroeder, Harry W. and David W. Rosberg. Drying rough rice with infra-red radiation. MP-354. Texas Agricultural Experiment Station. May, 1959.

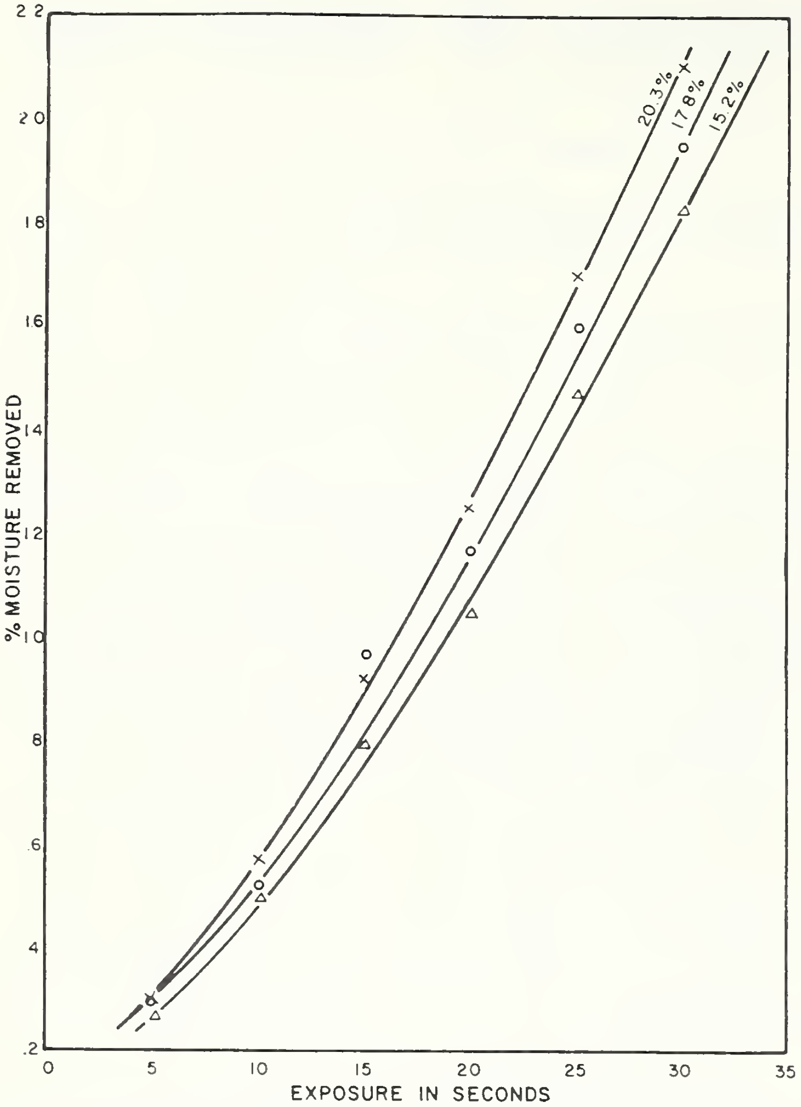

Figure 1. The relation between the per cent of moisture removed from Rexoro rough rice at three moisture-content levels and the infra-red irradiation period.

in cooler maintained at 7 degrees C. until used in drying tests. The rice from one storage container was used for each experiment.

In preparing an experiment, a can of rice was taken from the cooler and cleaned in a dockage tester. The rice was then mixed thoroughly by passing it through a Boerner Divider four times. The rice was then weighed into 200-g. samples and placed in pint Mason jars, each of which was numbered and assigned a treatment by use of a table of random numbers. Three samples were selected at random and two moisture-content determinations were made from each sample, using the two-stage air-oven method.[1] The six determinations were averaged and the resulting mean was considered the initial moisture content of the rice.

Samples which were to be irradiated at moisture levels below the initial moisture content were placed on screen-bottom trays and dried to a calculated weight at room temperatures. When the desired moisture level was attained the samples were returned to their original containers which were sealed until irradiated.

The samples were exposed to infra-red radiation at a distance of 6 inches from the bottom edge of the heater shade.[2]

All samples were allowed to reach room temperature before irradiation. The samples were irradiated on screen trays which had an area of one square foot. The rice was in a single layer of kernels when spread over the tray. A calculated energy input rate of 4,766 B.t.u. per hour per square foot was used in all treatments. Immediately after irradiation the sample was weighed, returned to its container and the temperature of the rice obtained by inserting a thermister surface temperature probe in the center of the mass. All samples were dried as closely as possible to an optimum moisture content for milling (12.5 per cent) as determined by weight, on screen trays at room temperature.

The samples were returned to their containers for a period of 24 hours or more before milling tests were made. The milling results were obtained from 125-g. aliquots of each sample, using a modified McGill portable mill and milling in two breaks at 15 pounds and 5 pounds pressure, respectively.

All sample weights were obtained with a Mettler Type K7 direct-reading balance and recorded to the nearest tenth of a gram.

The control samples were air dried to 12.5 per cent moisture at room temperature.

Experimental Results

Rexoro. The Rexoro rough rice at three moisture levels (20.3, 17.8 and 15.2 per cent) was exposed to infra-red radiation for six exposure periods of 5 to 30 seconds at 5-second intervals. The treatments were replicated four times and each replication was treated separately.

The mean temperatures reached during exposure ranged from 39° to 79° C. (Table 1). The lower the moisture content of the rice the higher the maximum temperature reached during a given exposure.

Highly significant differences between the maximum temperature of the rice, the per cent moisture loss, the drying rate and the yield of milled rice occurred between irradiation periods and between moisture levels (Tables 2 and 3).

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[1] American Association of Cereal Chemists. Cereal Laboratory Methods. Ed. VI. Published by the Association, St. Paul, Minnesota.

[2] A Schwank 48,000-B.t.u. input gas-fired infra-red heater, Model JU 524 DAL, was used in these experiments.

The per cent moisture loss during infra-red irradiation increased with length of the irradiation period and decreased with lower rice moisture content (Fig. 1.). The average drying rate was lowest for the 10-second exposure period (Table 2).

Significant differences between replications were observed for maximum temperature and head yield (Table 3). The temperature of the room in which the rice was irradiated and the initial temperature of the rice increased as the experiment progressed and can be assumed to be responsible for the significant differences between replications.

The yield of milled rice from the lot used in this experiment was very good (Fig. 2). The best irradiated treatment (15 seconds with 15.2 per cent moisture) gave a mean milling yield of 89.2 g. total milled rice and 83.7 g. head rice (71.4-67.0 per cent) or a 2 per cent increase in head rice over controls which milled 89.0 g. and 81.2 g. (71.2-65.0 per cent). Statistically, this is not significant; however, of 18 irradiated treatments, 13 produced mean head yields greater than that of the control. Of the five treatments lower than the control only three were significantly lower.

These five treatments received the longest irradiation. The highly significant interaction of moisture content and exposure period resulted in highly significant lower yields of head rice from the 25- and 30- second exposures as the moisture content of the rice decreased.

Bluebonnet 50. The Bluebonnet 50 rough rice at four moisture levels (21.6, 19.0. 16.6 and 14.1 per cent) was exposed to infra-red radiation for four exposure periods of 10-25 seconds in duration at 5-second intervals. The treatments were replicated three times and each replication treated separately.

The mean temperatures reached during irradiation exposure ranged from 53° to 85° C. (Table 4). The temperatures achieved in a given exposure period were inversely proportional to the moisture content of the rice as was also observed with Rexoro.

The differences between maximum temperature, drying rates, and yield of head rice were highly significant for irradiation periods and moisture content; the differences between

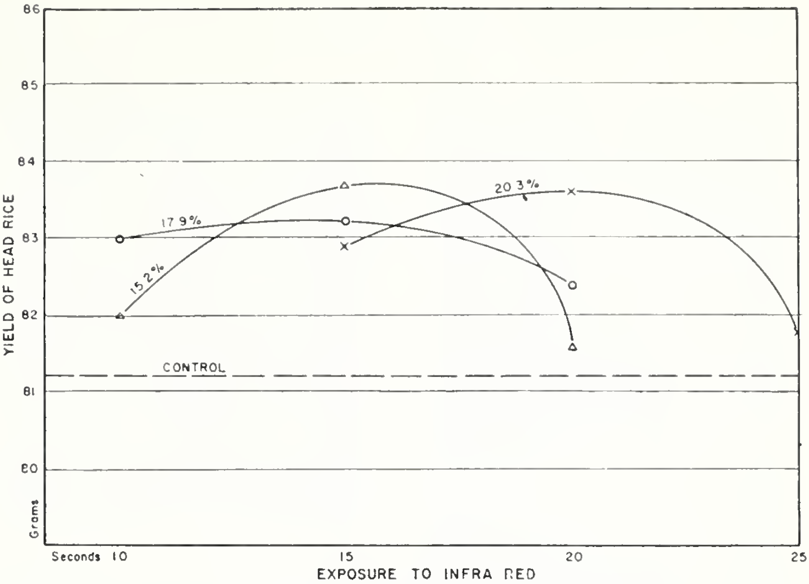

Figure 2. The effect of infra-red radiation on the yield of head rice from Rexoro rough rice in relation to the irradiation period and the initial moisture-content.

TABLE 1. The Effect of Initial Moisture-Content and Irradiation Period on Rexoro Rough Rice Dried with Infra-red radiation.[1]

—Treatment—					—Milling yield[3]—	
Irradiation period	Moisture content (wet-basis)	Max. temp.	Moisture loss	Drying rate[2] (water removed in 10 seconds)	Total milled rice	Head rice
Seconds	Percent	Degrees C.	Grams	Grams	Grams	Grams
5	20.3	39	.8	1.6	89.1	81.9
	17.8	43	.7	1.5	89.4	82.7
	15.2	47	.6	1.2	88.5	82.1
10	20.3	50	1.4	1.4	88.9	81.6
	17.8	52	1.3	1.3	89.4	83.0
	15.2	55	1.2	1.2	88.3	82.0
15	20.3	57	2.5	1.5	89.9	81.6
	17.8	60	2.0	1.3	89.3	83.2
	15.2	63	1.7	1.2	89.2	83.7
20	20.3	66	3.1	1.6	89.7	83.6
	17.8	67	2.9	1.5	89.4	82.4
	15.2	70	2.5	1.3	89.0	81.6
25	20.3	70	4.2	1.7	89.9	81.8
	17.8	74	3.8	1.5	89.8	77.9
	15.2	76	3.2	1.3	88.8	71.1
30	20.3	74	5.1	1.7	90.8	78.7
	17.8	77	4.5	1.5	88.7	65.7
	15.2	79	3.9	1.3	83.7	48.5
Controls					89.0[4]	81.2[4]
S.E.M.D.[5]		+/—1.8	+/—0.1	+/—0.02	+/—0.55	+/—1.85

[1] Given as the mean of 4 replications.

[2] From 200 g. rough rice and calculated to nearest 0.1 g.

[3] Yield from 125 g. of rough rice.

[4] Not included in analysis of variance Table 3.

[5] Standard error of the mean difference.

moisture loss were significant at the 5-per cent level for irradiation periods and highly significant for moisture content; and the differences between total yield of milled rice were significant at the 5-per cent level for exposures and not significant for moisture content (Tables 5 and 6).

The per cent moisture removed during exposure increased with the length of the exposure period and decreased with the moisture content of the rice, following the same trend as was observed for Rexoro (Fig. 3). The average drying rate was lowest for the 10-second exposure period.

Bluebonnet milled rice yields were not as high as those obtained with Rexoro. The Bluebonnet controls milled rice means were 81.8 g. and 70.3 g. total and head rice or 65.4 and 56.2 per cent, respectively, from 125 g. of rough rice. The best irradiated treatment (25 seconds with 21.6 per cent moisture rice) gave a total milling yield of 66.2 per cent and 59.0 per cent head rice, an increase of 2.8 per cent in head rice.

Discussion

The most important factors to consider in a study of rice-drying method are: (1) the time required to dry to a safe storage level or to optimum milling moisture content; (2) the effect on milling quality as measured by total and head yields; (3) the effect on appearance and cooking characteristics; and (4) the cost of the drying operation. The experiments reported here were designed primarily to study the first two factors.

The time required to dry rice to a given moisture level and the drying rate, will depend chiefly on the initial moisture content of the rice (Tables 2 and 5) and on the conditions to which the rice is subjected during the drying process.

The total drying time can be calculated from these data for a given lot of rice by selecting the most efficient irradiation period from the point of view of head yield and drying rate for the initial moisture content of the rice. As multiple drying passes appear to be mandatory, the irradiation period for subsequent passes would be calculated on the basis of the moisture content of the rice after the preceding pass. Summation of the irradiation periods would give the total drying time.

In drying rice by conventional means the drying rate is greater with rice of high moisture content than with rice of low moisture content. This fact is considered to be due to the presence of free water or loosely bound water in high moisture rice. Conversely, as the moisture content of the rice is lowered, the remaining water is more closely associated with the molecular constituents of the rice and is therefore more difficult to remove. The same general relationship occurs when rice is dried by infrared radiation instead of by heated air.

The temperature to which the rice is heated when irradiated also directly affects the drying rate. Tables 2 and 5 show that the higher temperatures reached as the exposure period was lengthened resulted in more rapid drying per unit time for both Rexoro and Bluebonnet 50. This relationship was true for exposures of 10 through 25 seconds, but for Rexoro (Table 2) the drying rate for the 5-second exposure was significantly greater than for the 10-second exposure. This is assumed to be caused by the rapid removal of free water near the kernel surface in the first few seconds of exposure to radiation. The data in Table 2 also show a leveling off of the drying rate after 25 seconds exposure under the conditions of this test. As more and more energy is required to remove the remaining water in the rice, the drying rate can be expected to decrease although the exposure period

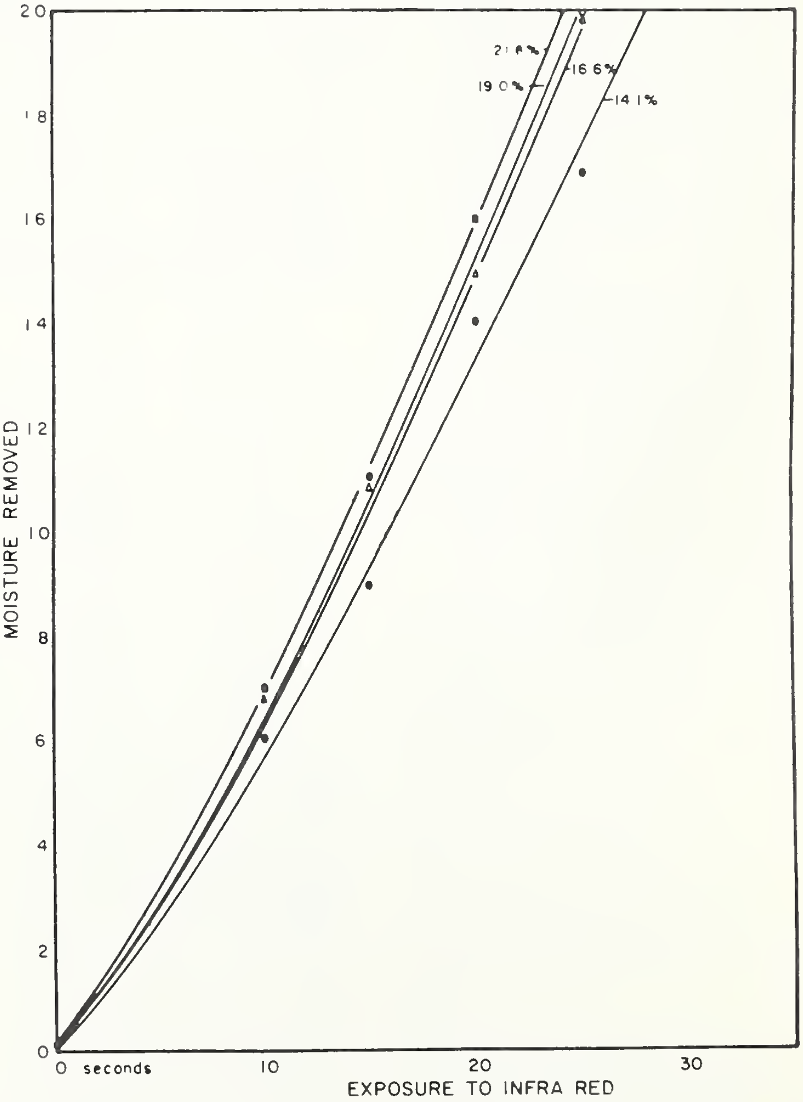

Figure 3. The relation between the per cent moisture removed from Bluebonnet 50 rough rice at four moisture-content levels and the irradiation period.

TABLE 2. A Comparison of the Average Effects of Irradiation Periods and Initial Moisture-Contents on Drying Results and Milling Yields of Rexoro Rough Rice Irradiated with Infra-red.

Factors and levels of treatment	Max. temp.	Moisture loss	Drying rate[1] (water removed in 10 seconds)	—Milling yield[2]— Total milled rice	Head rice
Irradiation period[3]	Degrees C	Grams	Grams	Grams	Grams
(1) 5 seconds	43	.7	1.4	89.0	82.2
(2) 10 seconds	52	1.3	1.3	88.9	82.2
(3) 15 seconds	60	2.0	1.3	89.5	83.3
(4) 20 seconds	68	2.8	1.4	89.4	82.5
(5) 25 seconds	73	3.7	1.5	89.5	76.9
(6) 30 seconds	77	4.5	1.5	87.2	64.3
S.E.M.D.[5]	+/—1.1	+/—0.06	+/—0.01	+/—0.32	+/—1.07
Moisture Content[4]					
(1) 20.3%	59	3.7	1.6	89.7	81.7
(2) 17.8%	62	3.4	1.4	89.3	79.2
(3) 15.2%	65	2.9	1.2	87.9	74.8
S.E.M.D.[5]	+/—0.9	+/—0.05	+/—0.01	+/—0.26	+/—0.87

[1] From 200 g. rough rice and caculated to nearest 0.1 g.

[2] Yield from 125 g. of rough rice.

[3] The mean of 4 replications of 3 treatments

[4] The mean of 4 replications of 6 treatments.

[5] Standard error of mean difference.

TABLE 3. The Statistical Significance of Main Factors and Interactions on the Effects of Drying Rexoro Rough Rice with Infra-red Radiation.

		— F —			—Milling yield	
Source of variation	D.F.	Max. temp.	Moisture loss	Drying rate	Total milled rice	Head rice
Replication	3	9.73**	1.50	2.50	1.07	3.33*
Irradiation period	5	303.81**	1286.50**	12.75**	8.64**	95.61**
Moisture content	2	26.67**	121.50**	95.00**	34.95**	42.88**
I.P. x M.C.	10	.40	8.50**	1.13	11.80**	21.97**
Error	51					
Total	71					

*Significant at the 5% level.

**Significant at the 1% level.

TABLE 4. The Effect of Initial Moisture-content and Irradiation Period on Bluebonnet 50 Rough Rice Dried with Infra-red Radiation[1].

—Treatment— Irradiation period	Moisture content (wet-basis)	Max. temp.	Moisture loss	Drying rate[2] (water removed in 10 seconds)	—Milling yield[3]— Total milled rice	Head rice
Seconds	Percent	Degrees C.	Grams	Grams	Grams	Grams
10	21.6	53	1.8	1.8	80.7	69.3
	19.0	55	1.6	1.6	80.3	69.5
	16.6	54	1.5	1.5	80.4	67.4
	14.1	55	1.2	1.2	82.6	70.8
15	21.6	60	2.7	1.8	81.4	70.3
	19.0	63	2.7	1.8	81.6	69.9
	16.6	66	2.4	1.6	81.1	68.7
	14.1	64	2.0	1.3	81.9	70.5
20	21.6	65	4.1	2.1	82.4	72.2
	19.0	68	3.6	1.8	81.6	70.4
	16.6	73	3.3	1.7	81.0	68.4
	14.1	76	2.8	1.4	81.1	68.2
25	21.6	72	5.2	2.1	82.8	73.8
	19.0	74	4.6	1.9	81.2	70.1
	16.6	81	4.2	1.7	80.2	60.2
	14.1	85	3.5	1.4	78.8	57.7
Controls					81.8[4]	70.3[4]
S.E.M.D.[5]		+/—2.0	+/—0.12	+/—0.08	+/—0.91	+/—1.09

[1] Given as the mean of 3 replications.

[2] From 200 g. rough rice and calculated to nearest 0.1 g.

[3] Yield from 125 g. of rough rice.

[4] Not included in analysis of variance Table 6.

[5] Standard error of mean difference.

and the resulting temperature of the rice are increased. Twenty-five seconds is therefore the optimum exposure period for the most efficient removal of water at the radiation intensity used.

Milling yields, both total and head rice, were significantly affected by the treatments used in these experiments. A significant decrease in the total yield of milled rice was associated with a very large decrease in yield of head rice.

The loss of small pieces and the abrasion of brokens in the milling process might account for the relatively small decrease in total milled rice. With Bluebonnet, although the total yield was affected significantly only by the interaction, the yield of head rice was affected significantly by three factors.

The range of irradiation periods for Bluebonnet (Table 4) was not as great as that of Rexoro (Table 1). If Bluebonnet had been irradiated for 30-socnds, a significant effect due to irradiation periods and moisture levels would probably have been shown by the analysis of variance.

Significant increases in yield of head rice over controls air dried at room temperature were not obtained for either Rexoro or Bluebonnet 50. Significant decreases in head yield occurred only under the most intense irradiation treatments; for Rexoro, in 5 out of 18 treatments and for Bluebonnet 50, in 2 out of 16 treatments. Uupublished studies have shown that conventional heated-air drying systems usually lower signifcantly the yield of head rice on the order of 2 to 8 per cent below that of controls dried at room temperature.[1] A drying method resulting in head-rice yields equal to that of controls dried at room temperature might be capable of increasing significantly the yield of head rice over that usually obtained with conventional drying systems. The authors reported[2] highly significant increases in head yield in a preliminary study with rice of very poor milling quality. The lots of Rexoro and Bluebonnet 50 used in the experiments reported here, however, were of very good milling quality. The controls milled with 6 and 9 per cent brokens, respectively.

For Rexoro, the highest mean yield of head rice disregarding moisture levels was obtained with a 15-second

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[1] Calderwood, D. L. and Harry W. Schroeder. Rice drying studies at Beaumont, Texas. 1958 and 1959.

[2] Schroeder, Harry W. and David W. Rosberg. Drying rough rice with infra-red radiation. MP-354. Texas Agricultural Experiment Station. May, 1959.

TABLE 5. A Comparison of the Average Effects of Irradiation Periods and Initial Moisture-Contents on Drying Results and Milling Yields of Bluebonnet 50 Rough Rice Irradiated with Infra-red.

Factors and levels of treatment	Max. temp.	Moisture loss	Drying rate[1] (water removed in 10 seconds)	—Milling yields[2]— Total milled rice	Head rice
Irradiation period	**Degrees C.**	**Grams**	**Grams**	**Grams**	**Grams**
(1) 10 seconds	54	1.5	1.5	81.0	69.3
(2) 15 seconds	63	2.5	1.6	81.5	69.8
(3) 20 seconds	71	3.5	1.7	81.5	69.8
(4) 25 seconds	78	4.4	1.8	80.8	65.4
S.E.M.D.[4]	+/—1.0	+/—0.06	+/--0.04	+/—0.45	+/—0.55
Moisture content[3]					
(1) 21.6%	63	3.5	1.9	81.8	71.4
(2) 19.0%	65	3.1	1.8	81.2	70.0
(3) 16.6%	69	2.9	1.6	80.7	66.2
(4) 14.1%	70	2.4	1.3	81.1	66.7
S.E.M.D.[4]	+/—1.0	+/—0.06	+/—0.04	+/—0.45	+/—0.55

[1] From 200 g. rough rice and calculated to nearest 0.1 g.

[2] Yield from 125 g. of rough rice.

[3] The mean of 3 replications of 4 treatments.

[4] Standard error of the mean difference.

exposure in which the rice reached a mean temperature of 60° C. (140° F.). The highest mean yield at all moisture levels for Bluebonnet 50 was also obtained with a 15-second exposure in which the rice reached a slightly higher temperature, 64° C. or 147° F. (Tables 2 and 4).

These temperatures are considerably higher than those usually attained in conventional rice driers. It should be pointed out, however, that these temperatures were reached in seconds and the rice did not remain at high temperatures very long. These data show a wide range of drying temperatures result in optimum or near optimum yields of head rice. Nevertheless, in the writers' opinion, they also indicate that control of drying, whether automatic or manual, would be best achieved by controlling the temperature of the rice.

The maximum mean head yields for Rexoro and Bluebonnet 50 at the highest moisture levels were obtained with 20- and 25-second exposures respectively. (Fig. 2, 4). The more rapid drying rate resulting in increased evaporative cooling prevented the temperatures of the rice from reaching the higher levels obtained with rice of lower moisture levels; therefore, the mean temperatures attained with the high-moisture rice at the longer exposure periods approached the mean temperatures attained during the 15-second exposure period, which gave the highest mean yield of head rice of all infra-red exposures.

There were no differences in color or appearance of the milled rice between any treatment and the control. The effect of infra-red drying on cooking characteristics was not studied in these experiments. Preliminary tests[1] have shown no detectable differences between infra-red and air-dried samples of rice in their reaction to the alkali swelling test, the iodine tests, and in rate of water absorption.

The scope of these experiments prevents an analysis of costs of drying which would be in any way comparable to commercial drying operations. The amount of fuel used was 4,766 B.t.u. input per hour per square

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[1] Conducted by John Halick, ARS, USDA, Rice-Pasture Experiment Station, Beaumont, Texas. Personal communication.

TABLE 6. The Statistical Significance of Main Factors and Interactions on the Effects of Drying Bluebonnet 50 Rough Rice with Infra-red Radiation.

		— F —				
					—Milling yield	
Source of variation	D.F.	Max. temp.	Moisture loss	Drying rate	Total milled rice	Head rice
Replication	2	.66	.50	.42	.84	2.57
Irradiation period	3	208.33**	928.50**	13.09**	1.37	29.65**
Moisture content	3	22.60**	124.50**	73.82**	2.16	42.05**
I.P. x M.C.	9	3.33**	8.00**	.65	2.83*	22.59**
Error	30					
Total	47					

*Significant at the 5% level.

**Significant at the 1% level.

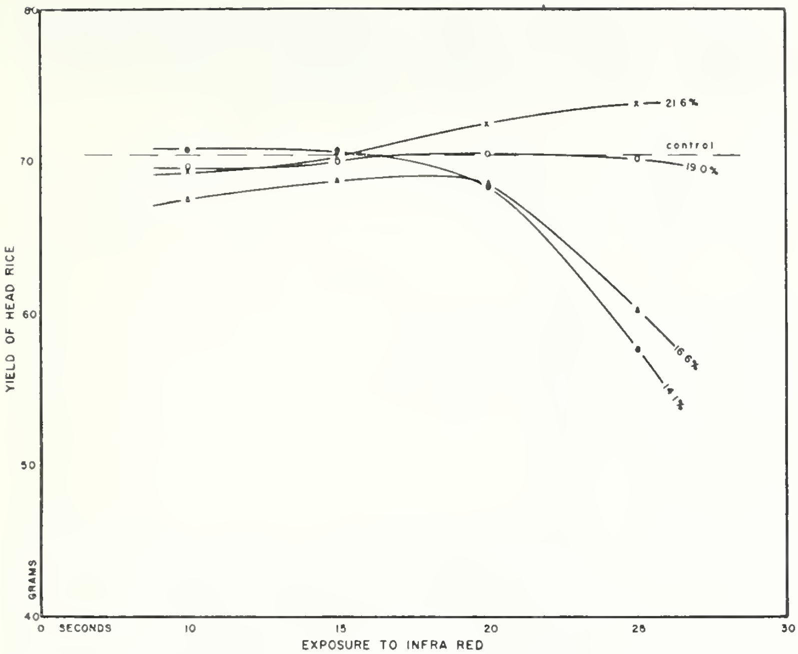

Figure 4. The effect of infra-red radiation on the yield of head rice from Bluebonnet 50 rough rice in relation to the irradiation period and the initial moisture-content.

foot of irradiated surface as calculated on the basis of the rated B.t.u. input of the heater and the area irradiated. These figures in conjunction with the data on drying rates could be used to estimate the fuel costs for drying a given amount of rice. It must be emphasized that such a cost estimate would not necessarily be accurate when applied to a workable large-scale infra-red drier.

Differences in the response to a given infra-red exposure between the two varieties of long-grained rice used in these experiments became apparent as the data were analyzed. The most obvious difference between varieties, the rate of drying, is easily seen by comparing Figures 1 and 3 or by reference to Tables 1 and 4. Bluebonnet 50, the light-hulled variety, has a faster drying rate than Rexoro, the dark-hulled variety. The one treatment factor common to both varieties is the length of exposure to infra-red at a given intensity level.

Therefore, the coefficients of correlation and regression of moisture content, temperature, drying rate, and head yield were calculated for all combinations of these variables. (Table 7).

In general the coefficients of correlation and regression were not significant at the 10- and 15-second exposure levels. The relation between variables at the lower exposure levels appears to be curvalinear. Bluebonnet 50 tended to approach a straight line relationship at shorter exposure periods than did Rexoro. The two varieties differed principally in the relation of temperature to moisture content, temperature to head yield, and drying rate to head yield (See Figure 5).

Whether these are true varietal differences or are merely differences which could be duplicated to the same or greater degree between lots within varieties has not been determined. However, these results suggest that a quick test to evaluate rice

TABLE 7. A Comparison of the Relations Between Pairs of Factors in Drying Rexoro and Bluebonnet 50 Rough Rice with Infra-red radiation.

—Variables—		Exposure	—Correlation—		—Regression—	
Independent	Dependent	(seconds)	Rexoro	Bluebonnet 50	Rexoro	Bluebonnet 50
Moisture content	Temperature	10	—.497	—.198	—.942	—.169
		15	—.677*	—.596*	—1.078*	—.640*
		20	—.610*	—.903**	—.737*	—1.509**
		25	—.705*	—.923**	—1.228*	—1.749**
Moisture content	Drying rate	10	.552	.867**	.044	.071**
		15	.920**	.875**	.073**	.067**
		20	.886**	.789**	.059**	.067**
		25	.953**	.921**	.084**	.086**
Moisture content	Head yield	10	—.128	—.160	—.073	—.099
		15	.228	.067	.163	.023
		20	.785**	.876**	.403**	.563**
		25	.952**	.939**	2.104**	2.318**
Temperature	Drying rate	10	—.296	—.194	—.012	—.019
		15	—.408	—.228	—.020	—.016
		20	—.531	—.799**	—.029	—.040**
		25	—.666*	—.888**	—.033*	—.044**
Temperature	Head yield	10	.488	—.110	.073	—.048
		15	.505	—.317	.179	—.091
		20	—.426	—.765**	—.180	—.294**
		25	—.801**	—.918**	—1.016**	—1.195**
Drying rate	Head yield	10	.057	—.186	.403	—1,405
		15	.496	—.019	1.779	—.085
		20	.583*	.832**	4.500*	6.316**
		25	.925**	.911**	23.300**	24.174**

*Significant at the 5% level.
**Significant at the 1% level.

varieties and selections on the basis of their drying characteristics could be developed.

Acknowledgment

The services of personnel of the Rice-Pasture Experiment Station, Beaumont, Texas, in obtaining rice for these experiments is gratefully acknowledged.

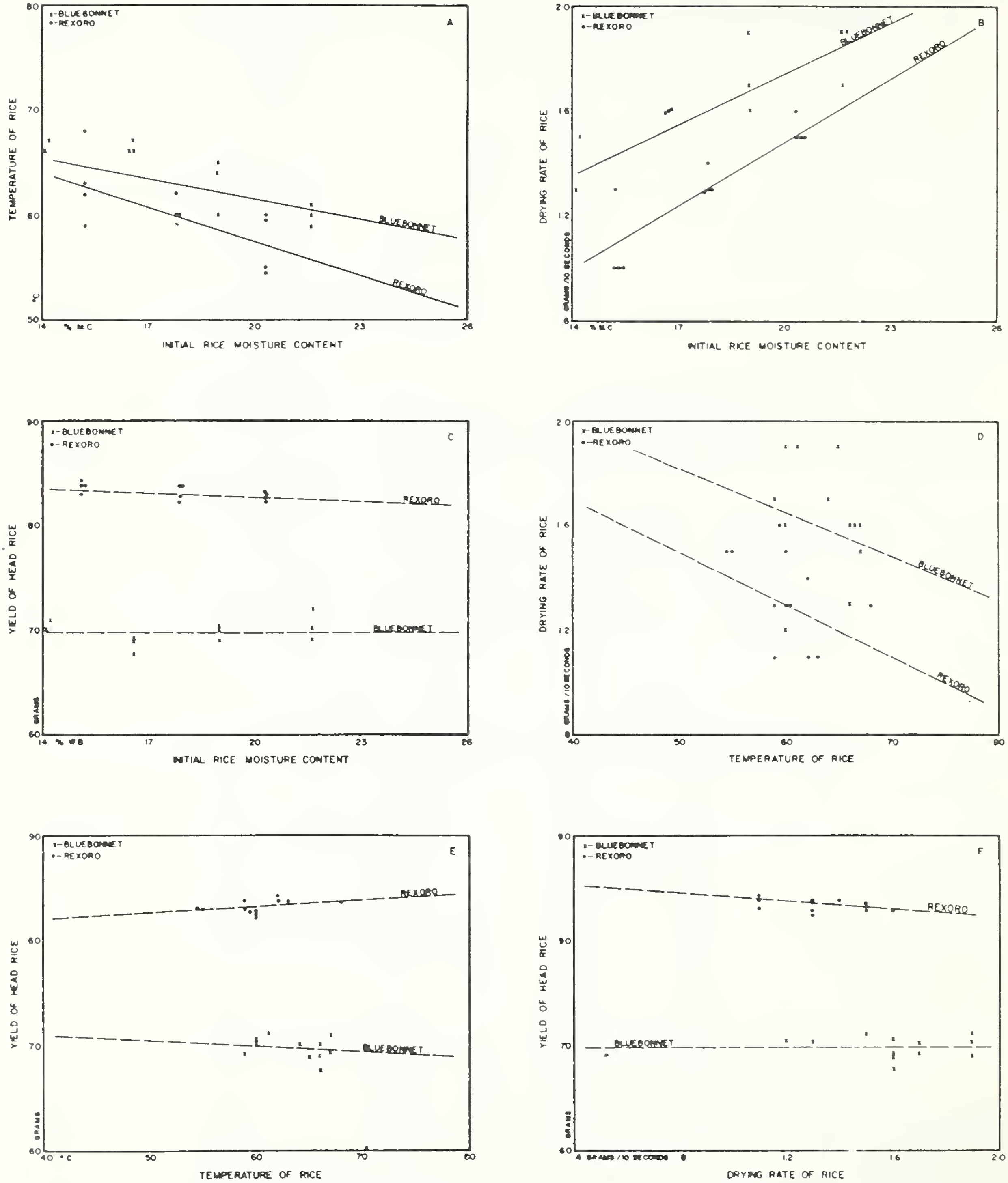

Figure 5. A comparison of the correlations between the rice moisture-content, the temperature of the rice, the drying rate, and the yield of head rice for Rexoro and Bluebonnet 50 rough rice irradiated for 15 seconds with infra-red. (A) Initial moisture-content and temperature, (B) Initial moisture-content and drying rate, (C) Initial moisture-content and yield of head rice, (D) Temperature and drying rate, (E) Temperature and yield of head rice, and (F) Drying rate and yield of head rice. A broken line indicates a nonsignificant linear correlation.

INFRA-RED DRYING OF ROUGH RICE

II. Short-Grain Type

Calrose and Caloro

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SUMMARY

Two varieties of short-grain rough rice, Calrose and Caloro, were irradiated with infra-red using a gas-fired ceramic panel heater as the source of infra-red. Two hundred gram samples of rice spread evenly over an area of one square foot were irradiated at a calculated energy input rate of 4,766 B.t.u. per hour per square foot in all treatments.

The rate of drying, for both varieties, decreased as the moisture content of the rice was decreased and increased as the irradiation period was increased from 10 seconds to 25 seconds. The drying rates for the irradiation periods varied from 0.9 to 1.9 grams of water removed per 10 seconds of irradiation for Calrose, and from 1.0 to 1.7 grams for Caloro.

The mean yield of head rice did not differ significantly from the controls for 9 out of 15 treatments for Calrose and for 8 of 15 treatments for Caloro. A significant increase in head yield was obtained by irradiating Caloro rough rice at 18.6 per cent moisture for five seconds.

Caloro absorbed more total energy than Calrose at all moisture levels as shown by temperatures of five to six degrees C. higher for a given treatment.

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INTRODUCTION

Moses (1) reported the commercial application of electric infra-red lamps to the drying of rough rice in California. He cited the higher cost of electric energy as the principal objection to this method of drying rice but did not quote comparative data on the effects on milling quality and drying rates of infra-red drying versus heated air drying.

Experimental drying of long-grain varieties of rough rice with infra-red radiation, using a gas-fired ceramic panel heater as an infra-red generator has been reported by Schroeder and Rosberg (2, 3). Their test results indicated that with infra-red drying the temperature of rice during drying, the drying rate, and the milling yield varies between varieties.

Whether such differences are true varietal characteristics or not, they reflect differences in the physical properties of the particular lots on which the data was obtained. The size and shape of the rice kernel are used to classify the commercially grown varieties of rice into the three grain types; short-, medium-, and long-grain rice. It appeared probable that kernel size and shape are at least partially a factor in the efficiency of the use of infra-red to dry rough rice. Therefore; experiments similar to those previously reported (3) were carried out on two varieties of short-grain rough rice.

Methods and Materials

A lot each of Calrose and Caloro short-grain rough rice was obtained from the Rice Experiment Station, University of California, Biggs, California. They were shipped by air immediately after harvest and arrived at moisture contents of 23.7 and 20.8 per cent respectively. The rice was stored in the shipping containers at seven degrees C. until the experiments could be started. There was no apparent deterioration during the storage period.

Preparation of sub-samples and the experimental plan of treatments was carried out in the manner previously described (3) for long-grain rice. The only variations in treatments between varieties were in the initial moisture levels of the rice before irradiation, and exclusion or addition of some irradiation periods.

To summarize the experimental plan, samples of Calrose were irradiated at three moisture levels for periods of 10 seconds to 30 seconds at 5-second increments and samples of Caloro were irradiated for periods of 5 seconds to 25 seconds at increments of 5 seconds. The samples were exposed to infra-red radiation at a distance of six inches from the bottom edge of the heater shade.[1] Two hundred grams per square foot of surface, based on Calrose at 23.7 per cent moisture and on Caloro at 20.8 per cent moisture, were irradiated for each treatment and each treatment was replicated three times. Samples were dried on screen trays at room temperature to uniform moisture contents before milling.

Moisture loss was calculated from sample weight. The temperature of the rice was taken immediately after irradiation with a thermister surface temperature probe. Milling yields were determined from 125-gram samples of rough rice milled at 12.5 (+/—0.2) per cent on a modified McGill portable mill.

Experimental Results

Calrose. The mean temperature per treatment of the rice at the end of the exposure period ranged from 49 to 83 degrees C. (Table 1). The rice temperature in a given exposure period increased as the initial moisture content decreased. The difference between mean temperatures for the 10- and 15-second exposure periods was not significant for consecutive drying stages, but the trend to higher temperatures between initial and final stages was clear. Errors in timing accurately such short exposures and the difficulty in measuring accurately the temperature of the rice before heat loss occurs could easily account for the error variation.

The differences between mean temperatures for replications were also significant. The means increased as the experiment progressed and they were directly proportional to the temperature of the rice before irradiation. The temperature of the rice and the room in which the experiment was conducted increased as the experiment progressed. There was no significant effect of replications on moisture loss, drying rate, or milling yields; therefore, the temperature differences due to replications under the conditions of this experiment did not seriously affect the drying test.

TABLE 1. The effect of Initial Moisture-Content and Irradiation Period on Calrose Rough Rice Dried with Infra-red radiation.[1]

—Treatment—					—Milling yield[3]—	
Irradiation period	Moisture content (wet-basis)	Max. temp.	Moisture loss	Drying rate[2] (water removed in 10 seconds)	Total milled rice	Head rice
Seconds	Percent	Degrees C.	Grams	Grams	Grams	Grams
	23.7	49	1.4	1.4	89.2	80.6
10	19.0	52	1.2	1.2	90.0	81.5
	14.8	53	.9	.9	89.9	82.6
	23.7	56	2.3	1.5	90.4	82.0
15	19.0	59	2.1	1.4	90.2	81.7
	14.8	60	1.4	.9	89.3	75.8
	23.7	60	3.3	1.6	90.4	83.0
20	19.0	64	2.9	1.4	90.0	79.1
	14.8	67	2.2	1.1	88.3	56.5
	23.7	65	4.6	1.9	91.8	81.5
25	19.0	70	3.8	1.5	90.2	73.8
	14.8	75	2.8	1.2	86.3	33.6
	23.7	67	5.5	1.8	92.4	85.2
30	19.0	76	4.8	1.6	90.3	64.5
	14.8	83	3.6	1.2	83.3	19.3
0	Controls				90.3[4]	82.0[4]
S.E.M.D.[5]		+/—1.6	+/—0.12	+/—0.02	+/—0.54	+/—2.47

[1] Given as the mean of 3 replications.
[2] From 200 g. rough rice and calculated to nearest 0.1 g.
[3] Yield from 125 g. of rough rice.
[4] Not included in analysis of variance Table 3.
[5] Standard error of the mean difference.

TABLE 2. A Comparison of the Average Effects of Irradiation Periods and Initial Moisture-Contents on Drying Results and Milling Yields of Calrose Rough Rice Irradiated with Infra-red.

				—Milling yield[2]—	
Factors and levels of treatment	Max. temp.	Moisture loss	Drying rate[1] (water removed in 10 seconds)	Total milled rice	Head rice
Irradiation period[3]	Degrees C	Grams	Grams	Grams	Grams
(1) 10 seconds	51	1.2	1.2	89.7	81.6
(2) 15 seconds	58	1.9	1.3	90.0	79.8
(3) 20 seconds	64	2.8	1.4	89.5	72.9
(4) 25 seconds	70	3.7	1.5	89.5	63.0
(5) 30 seconds	75	4.6	1.5	88.6	56.4
S.E.M.D.[5]	+/—0.9	+/—0.07	+/—0.01	+/—0.31	+/—1.42
Moisture Content[4]					
(1) 23.7%	59	5.7	1.4	90.8	82.5
(2) 19.0%	64	4.9	1.4	90.1	76.1
(3) 14.8%	67	2.2	1.3	87.4	53.6
S.E.M.D.[5]	+/—0.7	+/—0.05	+/—0.01	+/—0.24	+/—1.10

[1] From 200 g. rough rice and calculated to nearest 0.1 g.
[2] Yield from 125 g. of rough rice.
[3] The mean of 3 replications of 3 treatments.
[4] The mean of 3 replications of 5 treatments.
[5] Standard error of the mean difference.

TABLE 3. The Statistical Significance of Main Factors and Interactions of the Results of Drying Calrose Rough Rice at Three Moisture Levels.

		— F —				
					—Milling yield	
Source of variation	D.F.	Max. temp.	Moisture loss	Drying rate	Total milled rice	Head rice
Replication	2	5.73**	1.90	3.00	.83	.86
Irradiation period	4	214.48**	806.66**	41.00**	.51	116.54**
Moisture content	2	64.66**	279.52**	263.00**	112.26**	380.31**
I.P. x M.C.	8	4.81**	13.81**	1.00	27.55**	70.94**
Error	28					
Total	44					

**Significant at the 1% level.

The amount of water removed during irradiation was greater at the higher moisture contents within exposure periods and also increased with increased time of exposure. A similar relation occurred with treatments and the rate of drying (Table 1). The rate of drying increased significantly as the time of irradiation with infra-red was increased to 25 seconds. There was no significant change in the drying rate with 30 seconds of irradiation (Table 2).

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[1] A Schwank 48,000 Btu input gas-fired infra-red heater Model JU 524 DAL was used in these experiments.

Calrose rough rice at 23.7 and 19.0 per cent moisture content dried at approximately the same rate (Figure 1). The drying rate declined significantly at 14.8 per cent moisture content (Table 2). The interaction of irradiation period x moisture content did not affect the drying rate significantly but was significant for moisture loss (Table 3).

The mean yields of milled rice for the controls were 90.3 and 82.0 grams (72.2 and 65.6 per cent) respcetively of total and head rice. Four of 15 treatments resulted in yields of head rice as high or higher than the controls although none were significantly higher (Table 1). Head yield was greatly reduced by more than 10 seconds infra-red radiation with rice at 14.8 per cent moisture, but it showed a tendency to increase as the length of irradiation period was increased with rice of 23.7 per cent moisture. The interaction of irradiation period x moisture content on head yield of milled rice was highly significant (Table 3). Head yield increased as the moisture content was decreased during an irradiation period of 10 seconds but it decreased as the moisture content decreased for all irradiation periods of 15 seconds and longer (Figure 2).

Caloro. The relationships between moisture content and length of irradiation with infra-red to the temperature of the rice, water removal and milling yield (Tables 4 and 5) were similar to those obtained with Calrose rough rice. The differences between the varieties were primarily a matter of the degree in which temperature, etc., were affected by a given exposure to infra-red and will be discussed later.

Eight of the 15 treatments resulted in equal or greater head yields than were obtained from the control samples (Table 4). Caloro rough rice with 18.6 per cent moisture irradiated with infra-red for 5 seconds milled 3 grams more head rice (2.4 per cent) than the control and the difference is significant at the 5 per cent level.

Figures 3 and 4 illustrate the relation of length of the irradiation period and moisture content of the rice on drying and on yield of head rice.

TABLE 4. The Effect of Initial Moisture-Content and Irradiation Period on Caloro Rough Rice Dried with Infra-red Radiation.[1]

—Treatment—					—Milling yield[3]—	
Irradiation period	Moisture content (wet-basis)	Max. temp.	Moisture loss	Drying rate[2] (water removed in 10 seconds)	Total milled rice	Head rice
Seconds	Percent	Degrees C.	Grams	Grams	Grams	Grams
5	20.8	44	.8	1.7	89.5	68.7
	18.6	45	.6	1.2	90.3	70.2
	16.1	48	.6	1.2	90.8	69.8
10	20.8	53	1.5	1.5	90.0	69.1
	18.6	54	1.2	1.2	89.7	68.5
	16.1	55	1.0	1.0	91.0	69.8
15	20.8	61	2.4	1.6	89.4	67.5
	18.6	64	1.9	1.3	89.3	67.2
	16.1	68	1.7	1.1	88.9	63.2
20	20.8	69	3.1	1.6	87.7	59.5
	18.6	71	2.7	1.4	88.7	62.6
	16.1	73	2.3	1.2	83.8	45.3
25	20.8	74	4.3	1.7	83.4	43.2
	18.6	78	3.6	1.5	85.4	50.6
	16.1	82	3.0	1.2	70.3	22.3
0	Controls				90.1[4]	67.2[4]
S.E.M.D.[5]		+/—0.8	+/—0.12	+/—0.13	+/—1.00	+/—1.47

[1] Given as the mean of 3 replications.
[2] From 200 g. rough rice and calculated to nearest 0.1 g.
[3] Yield from 125 g. of rough rice.
[4] Not included in analysis of variance Table 6.
[5] Standard error of mean difference.

TABLE 5. A Comparison of the Average Effects of Irradiation Periods and Initial Moisture-Contents on Drying Results and Milling Yields of Caloro Rough Rice Irradiated with Infra-red.

Factors and levels of treatment	Max. temp.	Moisture loss	Drying rate[1] (water removed in 10 seconds)	—Milling yields[2]— Total milled rice	Head rice
Irradiation period	Degrees C.	Grams	Grams	Grams	Grams
(1) 5 seconds	45	.7	1.4	90.2	69.5
(2) 10 seconds	54	1.2	1.2	90.2	69.1
(3) 15 seconds	64	2.0	1.3	89.2	65.9
(4) 20 seconds	71	2.7	1.4	86.8	55.8
(5) 25 seconds	78	3.7	1.5	79.7	38.7
S.E.M.D.[4]	+/—0.5	+/—0.07	+/—0.07	+/—0.58	+/—0.85
Moisture Content[3]					
(1) 20.8%	60.3	2.4	1.6	88.0	61.6
(2) 18.6%	62.3	2.0	1.3	88.7	63.8
(3) 16.1%	65.3	1.7	1.1	85.0	54.1
S.E.M.D.[4]	+/—0.4	+/—0.05	+/—0.06	+/—0.45	+/—0.66

[1] From 200 g. rough rice and calculated to nearest 0.1 g.
[2] Yield from 125 g. of rough rice.
[3] The mean of 3 replications of 5 treatments.
[4] Standard error of the mean difference.

TABLE 6. The Statistical Significance of Main Factors and Interactions of the Results of Drying Caloro Rough Rice at Three Moisture Levels.

		— F —				
					—Milling yield	
Source of variation	D.F.	Max. temp.	Moisture loss	Drying rate	Total milled rice	Head rice
Replications	2	6.00**	2.50	1.55	.33	.11
Irradiation period	4	1536.00**	628.50**	2.64	116.07**	469.93**
Moisture content	2	97.00**	96.50**	35.09**	38.63**	119.13**
I.P. x M.C.	8	4.00**	6.00**	.40	27.08**	40.50**
Error	28					
Total	44					

**Significant at the 1% level.

Discussion

The influence of moisture content and length of irradiation with infra-red at a given intensity on milling yield has been discussed by Schroeder (3) in a report of drying long-grain rough rice with infra-red. These relations are similar to those observed in the experiments on short-grain rough rice reported here; therefore, this discussion will be largely confined to a comparison of the difference observed between: (1) Calrose and Caloro and (2) long-grain rice and short-grain rice.

A direct comparison of the drying data for Calrose and Caloro as given in Tables 1, 2, 4 and 5 cannot be made since the moisture content levels at which the samples were irradiated were not identical. The two varieties were both irradiated for periods of 10 to 25 seconds at the same radiation intensity so the effects of infra-red radiation can best be evaluated from the standpoint of varietal differences by a comparison of the correlation of pairs of variables within each irradiation period (Table 7).

Comparisons of the effect of infra-red radiation could be made for each of the irradiation periods of from 10 seconds to 25 seconds; however, this discussion will be confined to a comparison between varieties on the results obtained with a 15-second irradiation period (Figure 5). The correlations were not significant for shorter periods of irradiation and the yield of head rice was decreased significantly with the longer periods. The relationships between pairs of variables is usually curvilinear for the shorter irradiation periods but tends to become linear as the period of irradiation is lengthened.

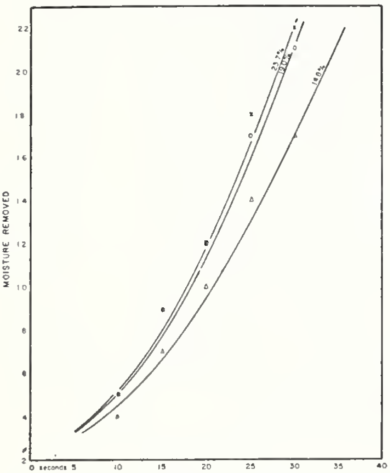

Figure 1. The relation between the per cent of moisture removed from Calrose rough rice at three moisture-content levels and the infra-red irradiation period

Caloro rough rice absorbed infra-red radiation more efficiently than Calrose. Caloro reached a temperature of 5 to 6 degrees C. higher than Calrose in a 15-second exposure to infra-red. The moisture content of the rice at the beginning of the irradiation period had approximately the same effect on the temperature reached by both varieties. Both varieties also dried at about the same rate when heated to 50 degrees C., but Caloro dried at a more rapid rate as the temperature increased. The yield of head rice was decreased more rapidly with Calrose as the temperature of the rice increased although the correlation between temperature and drying rate was not significant for a 15-second exposure since the relation appears to be curvilinear.

The drying rate of Caloro increased in relation to that of Calrose as the moisture content increased. The correlation between drying rate and head yield was highly significant for Calrose but was not significant for Caloro. Yield of head rice increased with an increasing rate of drying in the case of Calrose but appears to follow a curvilinear pattern peaking at drying rates of approximately 1.3 grams per 10-second irradiation with infra-red. The yield of head rice is also significantly correlated with the moisture content of the rice at the time of irradiation. The correlation coefficients are 0.806 and 0.835 respectively for Calrose and Caloro.

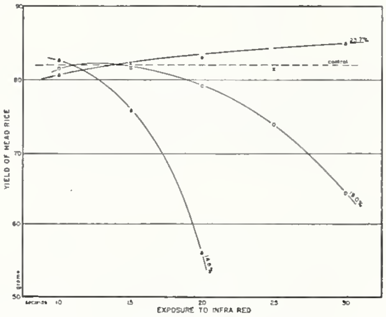

Figure 2. The effect of infra-red radiation on the yield of head rice from Calrose rough rice in relation to the irradiation period and the initial moisture-content.

The greatest difference in yield of head rice between the two varieties is the original difference in milling quality of the two lots of rice as shown by the milling yields of the controls. Calrose controls milled approximately 15 grams more head rice than Caloro controls and this difference persisted with some minor variations regardless of treatment. The original milling quality difference may be reflecting both hereditary varietal differences and differences in quality due to environmental factors during the growing season or during harvest. It was noted that the Caloro rice contained a high per cent of chalky kernels and the lot of Calrose, almost none.

A comparison of the data given in this paper with similar data previously reported for the long-grain varieties, Rexoro and Bluebonnet 50, showed greater differences between varieties within grain types than were found between grain types. The comparison was made on the basis of the correlations between initial moisture content as the independent variable and temperature, drying rate, and yield of head rice as the dependent variables again using only the data for the 15-second irradiation period.

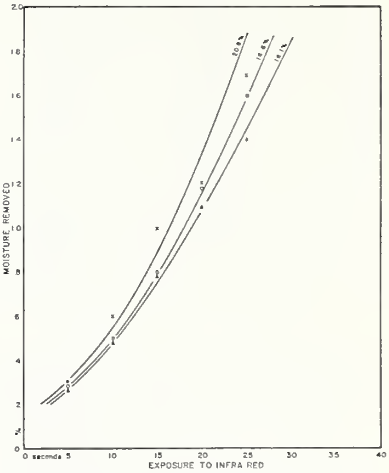

Figure 3. The relation between the per cent of moisture removed from Caloro rough rice at three moisture-content levels and the infra-red irradiation period.

Caloro and Bluebonnet 50 reached higher temperatures at all moisture levels than Calrose and Rexoro. Bluebonnet 50 attained the highest drying rate of the four varieties, losing on an average of approximately 0.3 grams more water per 10 seconds of irradiation at all moisture levels than the other three varieties. The drying rate for Rexoro was higher at moisture contents under 20 per cent but was intermediate between Caloro and Calrose at moisture contents above 20 per cent.

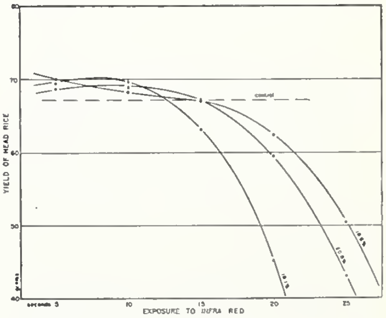

Figure 4. The effect of infra-red radiation on the yield of head rice from Caloro rough rice irradiated at three moisture-content levels in relation to the irradiation period and the initial moisture-content.

Acknowledgements

The cooperation of D. W. Finfrock, Rice Experiment Station, University of California, in supplying the rice used in these experiments is acknowledged.

These studies were made in cooperation with the Texas Agricultural Experiment Station.

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2. Schroeder, Harry W. and David W. Rosberg. Drying rough rice with infra-red radiation. Texas Agr. Expt. Sta. MP-354 1959.
3. Schroeder, Harry W. and David W. Rosberg. Infra-red drying of rough rice. I. Long-grain type; Rexoro and Bluebonnet 50. The Rice Journal, Vol. 63, No. 12, November, 1960.

TABLE 7. A Comparison of the Relations Between Pairs of Factors in Drying Calrose nad Caloro Rough Rice with Infra-red Radiation.

—Variables—		Exposure	—Correlation—		—Regression—	
Independent	Dependent	(seconds)	Calrose	Caloro	Calrose	Caloro
Moisture content	Temperature	10	—.577	—.833**	—.458	—.431**
		15	—.746*	—.857**	—.422*	—1.489**
		20	—.893**	—.955**	—.711**	—.922**
		25	—.885**	—.959**	—1.159**	—1.706**
Moisture content	Drying rate	10	.948**	.876**	.052**	.099**
		15	.945**	.832**	.066**	.105**
		20	.942**	.944**	.059**	.093**
		25	.986**	.986**	.078**	.106**
Moisture content	Head yield	10	—.744*	—.224	—.220*	—.157
		15	.806**	.835**	.684**	.923**
		20	.899**	.702*	2.925**	2.800*
		25	.914**	.727*	5.284**	4.587*
Temperature	Drying rate	10	—.550	—.671*	—.038	—.146*
		15	—.633	—.671*	—.073	—.049*
		20	—.870**	—.852**	—.069**	—.087**
		25	—.918**	—.913**	—.056**	—.055**
Temperature	Head yield	10	.861**	.216	.322**	.292
		15	—.483	—.632	—.676	—.402
		20	—.806**	—.759*	—3.291**	—3.136*
		25	—.827**	—.748*	—3.653**	—2.659*
Drying rate	Head yield	10	—.779*	—.038	—4.108*	—.238
		15	.892**	.488	10.633**	.042
		20	.903**	.640	47.213**	26.188
		25	.923**	.662	66.882**	38.256

*Significant at the 5% level.
**Significant at the 1% level.

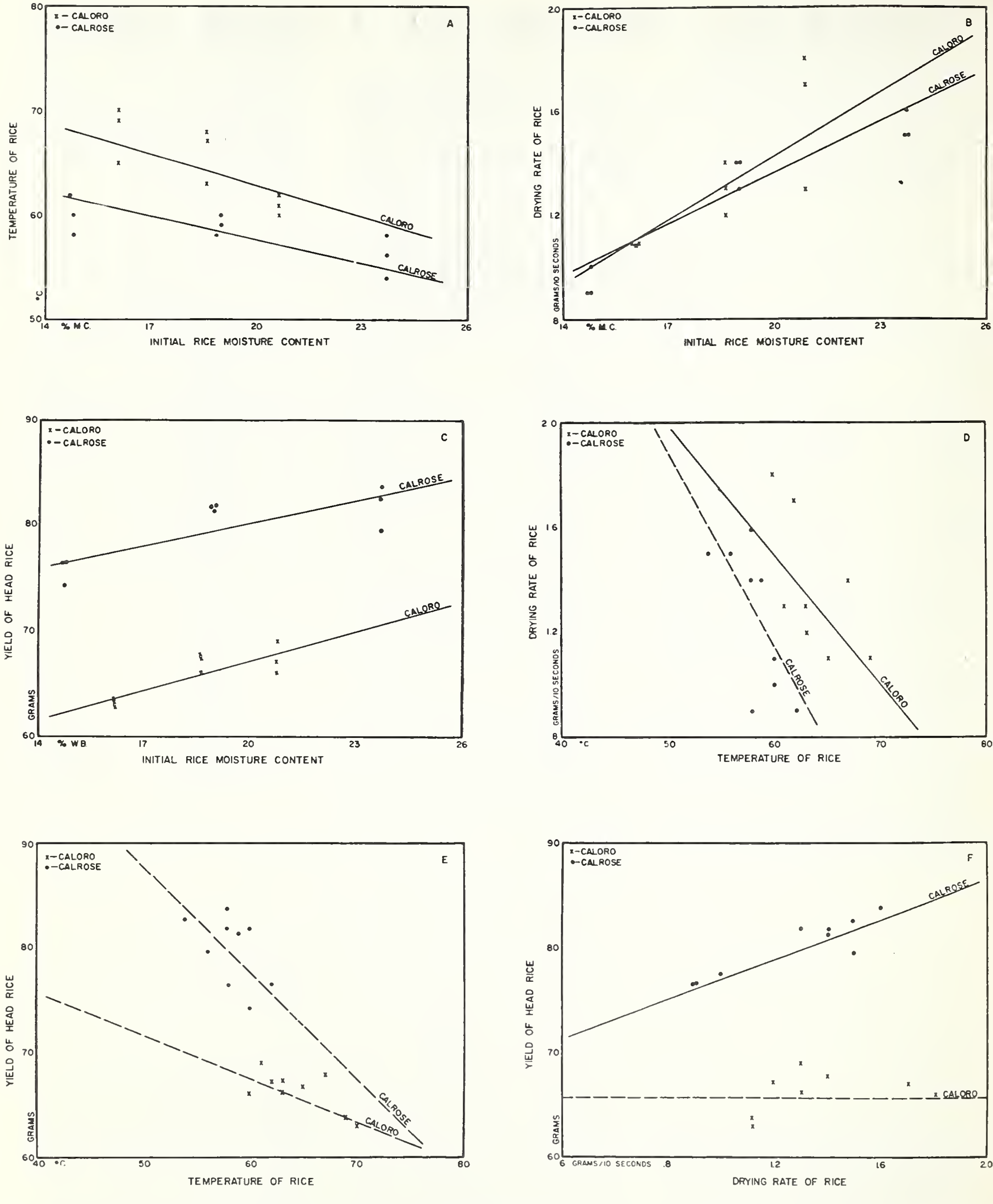

Figure 5. A comparison of the correlations between the rice moisture content, the temperature of the rice, the drying rate, and the yield of head rice for Calrose and Caloro rough rice irradiated for 15 seconds with infra-red. (A) Initial moisture-content and temperature, (B) Initial moisture-content and drying rate, (C) Initial moisture-content and yield of head rice, (D) Temperature and drying rate, (E) Temperature and yield of head rice and (F) Drying rate and yield of head rice. A broken line indicates a non-significant linear correlation.

INFRA-RED DRYING OF ROUGH RICE

III. Medium-Grain Type
Nato and Magnolia

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SUMMARY

Two varieties of medium-grain rough rice, Nato and Magnolia, were irradiated with infra-red from a gas-fired ceramic panel heater. Two hundred gram samples of rice spread evenly over an area of one square foot were irradiated at a calculated energy input rate of 4,766 B.t.u. per hour per square foot in all treatments.

The rate of drying, for both varieties, decreased as the initial moisture content of the rice decreased, and increased as the irradiation period was increased from 10 to 25 seconds. The drying rate for the irradiation periods ranged from 1.2 to 1.9 grams of water removed per 10 seconds of irradiation for Nato, and from 1.3 to 1.6 grams for Magnolia (15, 20, and 25 second irradiation periods).

The mean yield of head rice did not differ significantly from the yield of the controls for 12 of 18 treatments for Nato and for 6 of 12 treatments for Magnolia.

At all moisture levels, the higher temperatures of Nato rice indicated that it absorbed more total energy from a given radiation treatment than Magnolia.

* * *

Introduction

Experimental drying of long-grain and short-grain rough rice has been reported by Schroeder and Rosberg (2) and by Schroeder (1). This paper, the third of the series, presents similar data derived from experimental drying of two medium-grain varieties, Nato and Magnolia.

Methods and Materials

Eight gallons of Nato rough rice and eight gallons of Magnolia rough rice were obtained from commercial dryers in Texas and Louisiana. The rice was placed in friction top tins at the dryer. The tins of rice were then taken to College Station, Texas, by automobile where they were refrigerated at 45 degrees F. The Nato rough rice contained 21.3 percent, and the Magnolia, 18.9 percent moisture when their respective drying experiments were started. No deterioration in quality of either variety was apparent during storage.

Preparation of sub-samples and the experimental plan of treatments were similar to those described for long-grain rice(2). To summarize the experimental plan, samples of Nato were irradiated at three moisture levels for periods of 10 to 35 seconds at 5-second increments and samples of Magnolia were irradiated at three moisture levels for periods of 15 to 30 seconds at 5-second increments. The samples were exposed to infra-red radiation at a distance of 6 inches from the bottom edge of the shade of the infra-red heater[1] at the calculated energy input rate of 4,766 B.t.u. per hour per square foot of irradiated surface. Two hundred grams per square foot of surface, based on Nato at 21.3 and on Magnolia at 18.9 percent moisture, were irradiated for each treatment and replicated three times. Samples were dried to uniform moisture contents for milling on screen trays at room temperature.

Moisture loss was calculated from sample weight. The temperature of the rice was taken immediately after irradiation with a thermister surface temperature probe. Milling yields were determined from 125-gram samples of rough rice milled at 12.5 (+/—0.2) percent moisture on a modified McGill portable mill.

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[1] A Schwank, 48,000 B.t.u. input gas-fired infra-red heater, Model JU 524 DAL, was used in these experiments.

Experimental Results

Nato. The Nato rough rice at three moisture levels (21.3, 17.9, and 15.1 percent) was irradiated with infra-red for six exposure periods of 10 to 35 seconds in 5-second increments.

The relation of irradiation period and moisture content to the maximum temperature of the rice was similar to that reported for long-grain rice (2) and short-grain rice (1). The rice reaches a higher temperature as the irradiation period is increased and as the moisture content is decreased (Table 2). The significant interaction of irradiation period and moisture content indicates that the moisture content has a different effect on temperature during some irradiation periods than during others (Table 3).

The moisture loss during irradiation and the drying rate were also affected significantly by the irradiation period and by the moisture content (Fig. 1 and Tables 1 and 2) but the interaction between the two factors was significant for moisture loss and not significant for drying rate (Table 3).

The controls milled 89.7 grams total milled rice and 84.4 grams of head rice (71.8 and 67.5 percent, Table 1). The best mean yield from irradiated samples, 89.4 grams total milled rice and 84.4 grams head rice (71.5 and 67.5 percent), was obtained with 15.1-percent rice irradiated for 15 seconds. Head rice yields were significantly reduced by irradiation of 15.1-percent rice for 25, 30, and 35 seconds; by irradiation of 17.9-percent rice for 30 and 35 seconds; and by irradiation of 21.3-percent rice for 35 seconds (Fig. 2 and Table 1). The interaction of irradiation periods and moisture contents had a significant affect on the yield of milled rice (Table 3).

Magnolia. The lot of Magnolia rough rice was received originally at 2.4 percent lower moisture content than the lot of Nato. It was therefore irradiated at moisture levels of 18.9, 16.5, and 14.4 percent at four irradiation periods from 15 to 30 seconds at 5-second increments.

The maximum temperature resulting from irradiation with infra-red varied from 59 to 84 degrees C. The relation between temperature and irradiation period and moisture content (Table 4 and 5) was similar to that reported for Nato (Table 1 and 2) except that the interaction of the two factors did not have a significant effect on temperature.

The moisture loss and the drying

TABLE 1. The Effect of Initial Moisture-Content and Irradiation Period on Nato Rough Rice Dried with Infra-red radiation.[1]

—Treatment—					—Milling yield[3]—	
Irradiation period	Moisture content (wet-basis)	Max. temp.	Moisture loss	Drying rate[2] (water removed in 10 seconds)	Total milled rice	Head rice
Seconds	Percent	Degrees C.	Grams	Grams	Grams	Grams
10	21.3	54	1.7	1.7	89.3	83.8
	17.9	57	1.3	1.3	89.3	84.2
	15.1	58	1.1	1.1	88.5	84.0
15	21.3	61	2.6	1.7	88.7	83.4
	17.9	66	2.1	1.4	89.3	83.9
	15.1	67	1.7	1.2	89.4	84.4
20	21.3	68	3.5	1.7	88.1	81.3
	17.9	71	2.9	1.5	89.3	83.1
	15.1	78	2.6	1.3	88.6	79.7
25	21.3	75	4.6	1.9	89.6	82.5
	17.9	79	3.9	1.6	89.3	80.5
	15.1	82	3.3	1.3	87.7	71.1
30	21.3	80	5.7	1.9	90.4	80.4
	17.9	84	4.9	1.6	89.6	76.2
	15.1	88	4.1	1.4	85.1	56.3
35	21.3	82	6.9	1.9	90.9	75.0
	17.9	90	5.7	1.6	89.1	64.7
	15.1	96	4.9	1.4	81.7	36.0
Controls					89.7[4]	84.4[4]
S.E.M.D.[5]		+/—1.5	+/—.12	+/—.05	+/—.66	+/—3.27

[1] Given as the mean of 4 replications.
[2] From 200 g. rough rice and calculated to nearest 0.1 g.
[3] Yield from 125 g. of rough rice.
[4] Not included in analysis of variance Table 3.
[5] Standard error of the mean difference.

TABLE 2. A Comparison of the Average Effects of Irradiation Periods and Initial Moisture-Contents on Drying Results and Milling Yields of Nato Rough Rice Irradiated with Infra-red.

				—Milling yield[2]—	
Factors and levels of treatment	Max. temp.	Moisture loss	Drying rate[1] (water removed in 10 seconds)	Total milled rice	Head rice
Irradiation period[3]	Degrees C.	Grams	Grams	Grams	Grams
(1) 10 seconds	56	1.4	1.4	89.1	84.0
(2) 15 seconds	65	2.1	1.4	89.1	83.9
(3) 20 seconds	72	3.0	1.5	88.7	81.4
(4) 25 seconds	78	4.0	1.6	88.9	78.0
(5) 30 seconds	84	4.9	1.6	88.4	71.0
(6) 35 seconds	89	5.8	1.7	87.2	58.6
S.E.M.D.[5]	+/—.9	+/—.07	+/—.03	+/—.38	+/—1.89
Moisture Content[4]					
(1) 21.3%	70	4.2	1.8	89.5	81.1
(2) 17.9%	74	3.5	1.5	89.3	78.8
(3) 15.1%	78	3.0	1.3	86.8	68.6
S.E.M.D.[5]	+/—.6	+/—.05	+/—.02	+/—.27	+/—1.34

[1] From 200 g. rough rice and calculated to nearest 0.1 g.
[2] Yield from 125 g. of rough rice.
[3] The mean of 4 replications of 3 treatments.
[4] The mean of 4 replications of 6 treatments.
[5] Standard error of the mean difference.

TABLE 3. The Statistical Significance of Main Factors and Interactions on the Effects of Drying Nato Rough Rice with Infra-red Radiation.

		— F —				
					—Milling yield—	
Source of variation	D.F.	Max. temp.	Moisture loss	Drying rate	Total milled rice	Head rice
Replication	2	.75	.00	.23	.52	.68
Irradiation period	5	415.28**	1274.00**	25.70**	6.65**	54.44**
Moisture content	2	88.66**	322.50**	288.55**	61.45**	49.55**
I.P. x M.C.	10	3.43**	11.50**	.84	18.35**	13.00**
Error	34					
Total	53					

**Significant at the 1% level.

rates (Fig. 3 and Table 4) also followed the same general pattern described for Nato, but the interaction of irradiation period and moisture content was not significant for either the moisture loss or the drying rates (Table 6).

The controls milled 87.4 grams total milled rice and 75.1 grams head rice (69.9 and 60.1 percent, Table 4). The best mean yield for irradiated samples, 87.6 grams total milled rice and 74.1 grams head rice (70.8 and 59.3 percent), was obtained with 14.4 percent rice irradiated for 15 seconds. Head rice yields were significantly reduced by irradiation of rice at 14.4 percent moisture for periods of 20, 25, and 30 seconds; by irradiation of rice at 16.5 percent

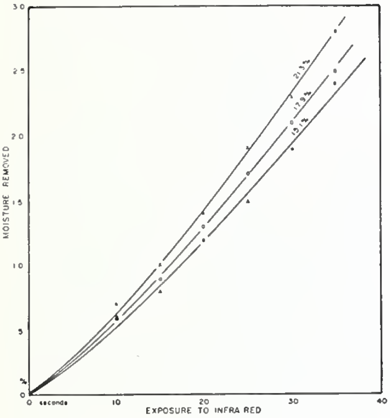

Figure 1. The relation between the per cent of moisture removed from ato rough rice at three moisture-content levels and the infrared irradiation period.

TABLE 4. The Effect of Initial Moisture-Content and Irradiation Period on Magnolia Rough Rice Dried with Infra-red Radiation.[1]

—Treatment—					—Milling yield[3]—	
Irradiation period	Moisture content (wet-basis)	Max. temp.	Moisture loss	Drying rate[2] (water removed in 10 seconds)	Total milled rice	Head rice
Seconds	Percent	Degrees C.	Grams	Grams	Grams	Grams
15	18.9	59	2.4	1.6	87.6	73.6
	16.5	61	2.2	1.4	87.9	74.0
	14.4	65	2.0	1.3	87.6	74.1
20	18.9	66	3.1	1.5	88.1	72.3
	16.5	67	3.0	1.5	87.2	71.1
	14.4	71	2.6	1.3	86.7	69.1
25	18.9	71	4.1	1.6	87.6	71.5
	16.5	75	3.8	1.5	86.9	65.9
	14.4	78	3.3	1.3	85.1	54.6
30	18.9	78	5.0	1.7	88.5	67.3
	16.5	80	4.7	1.6	85.8	54.2
	14.4	84	4.0	1.3	81.8	37.6
Controls					87.4[4]	75.1[4]
S.E.M.D.[5]		+/—1.6	+/—.14	+/—.04	+/—.45	+/—2.01

[1] Given as the mean of 3 replications.
[2] From 200 g. rough rice and calculated to nearest 0.1 g.
[3] Yield from 125 g. of rough rice.
[4] Not included in analysis of variance Table 6.
[5] Standard error of the mean difference.

TABLE 5. A Comparison of the Average Effects of Irradiation Periods and Initial Moisture-Contents on Drying Results and Milling Yields of Magnolia Rough Rice Irradiated with Infra-red.

				—Milling yields[2]—	
Factors and levels of treatment	Max. temp.	Moisture loss	Drying rate[1] (water removed in 10 seconds)	Total milled rice	Head rice
Irradiation period	Degrees C.	Grams	Grams	Grams	Grams
(1) 15 seconds	62	2.2	1.4	87.7	73.9
(2) 20 seconds	68	2.9	1.4	87.3	70.8
(3) 25 seconds	75	3.7	1.5	86.5	64.0
(4) 30 seconds	80	4.6	1.5	85.4	53.1
S.E.M.D.[4]	+/—.9	+/—.08	+/—.03	+/—.26	+/—1.16
Moisture content[3]					
(1) 18.9%	68	3.6	1.6	88.0	71.2
(2) 16.5%	71	3.4	1.5	87.0	66.3
(3) 14.4%	75	3.0	1.3	85.3	58.9
S.E.M.D.[4]	+/—.8	+/—.07	+/—.02	+/—.22	+/—1.00

[1] From 200 g. rough rice and calculated to nearest 0.1 g.
[2] Yield from 125 g. of rough rice.
[3] The mean of 3 replications of 4 treatments.
[4] Standard error of the mean difference.

TABLE 6. The Statistical Significance of Main Factors and Interactions on the Effects of Drying Magnolia Rough Rice with Infra-red Radiation.

		— F —				
					—Milling yield—	
Source of variation	D.F.	Max. temp.	Moisture loss	Drying rate	Total milled rice	Head rice
Replication	2	4.75*	.33	.33	6.90**	.98
Irradiation period	3	148.00**	320.33**	3.90*	32.10**	126.38**
Moisture content	2	30.75**	43.67**	80.43**	71.77**	75.87**
I.P x M.C.	6	.50	2.33	1.00	20.87**	23.65**
Error	22					
Total	35					

*Significant at the 5% level.
**Significant at the 1% level.

moisture for periods of 25 and 30 seconds; and by irradiation of rice at 18.9 percent moisture for 30 seconds (Fig. 4 and Table 4). All other treatments resulted in head rice yields which were not significantly different from the controls. The interaction of irradiation periods and moisture contents had a significant effect on the yield of milled rice (Table 6).

Discussion

The general relation of irradiation period and moisture content to infrared drying of medium-grain rough rice is similar to that reported for long-grain rice (2) and for short-grain rice (1). This discussion will be confined to the differences observed between Nato and Magnolia, based on the data reported in this paper, with some references to differences between long-short-, and medium-grain type, based on the data from the other two papers comprising this series of reports.

The analysis of variance for Nato indicated a highly significant interaction of irradiation period and moisture content affecting temperature, moisture loss, drying rate, and milling yields (Table 3). For Magnolia the interaction was significant only

TABLE 7. A Comparison of the Relations Between Pairs of Factors in Drying Nato and Magnolia Rough Rice with Infra-red Radiation.

—Variables—		Exposure (seconds)	—Correlation—		—Regression—	
Independent	Dependent		Nato	Magnolia	Nato	Magnolia
Moisture content	Temperature	10	—.750*		—.598*	
		15	—.927**	—.841**	—.926**	—1.456**
		20	—.920**	—.786*	—1.602**	—1.030*
		25	—.294	—.793*	—1.076	—1.712*
Moisture content	Drying rate	10	.924**		.092**	
		15	.978**	.380	.091**	.026
		20	.945**	.891**	.071**	.052**
		25	.989**	.922**	.091**	.067**
Moisture content	Head yield	10	—.135		—.029	
		15	—.473	—.172	—.157	—.117
		20	.382	.594	.232	.732
		25	.843**	.952**	1.808**	3.846**
Temperature	Drying rate	10	—.627		—.078	
		15	—.859**	—.906**	—.080**	—.036**
		20	—.826**	—.665*	—.036**	—.030*
		25	—.290	—.677*	—.007	—.023*
Temperature	Head yield	10	.497		.133	
		15	.593	—.208	.197	.081
		20	—.595	.408	—.208	.211
		25	—.250	—.704**	—.146	—1.283**
Drying rate	Head yield	10	.106		.288	
		15	—.478	—.270	—1.720	—2.714
		20	.170	—.109	1.406	—1.300
		25	.894**	.920**	20.837**	—49.625**

*Significant at the 5% level.
**Significant at the 1% level.

for milling yields (Table 6). A significant interaction indicates that the moisture content has a different effect at one irradiation period than at another. Nato rough rice was irradiated for two periods (10 and 35 seconds) which were not included in the experimental drying of Magnolia. Irradiation of Magnolia for 10 and 35 seconds might have resulted in significant interactions.

A comparison of the relations between pairs of factors for each irradiation period from 10 to 25 seconds is given in Table 7. These relations for the 15-second period are illustrated (Fig. 5) in order to emphasize the differences between varieties and simplify the discussion.

For the 15-second irradiation period the temperature of Magnolia was lower than that of Nato for all moisture contents (Fig. 5). In a 25-second irradiation period, a linear correlation between moisture content and temperature was observed for Magnolia but not for Nato (Table 7). These data indicate that differences in the absorption of total energy or possibly just infra-red energy, occur between the two varieties.

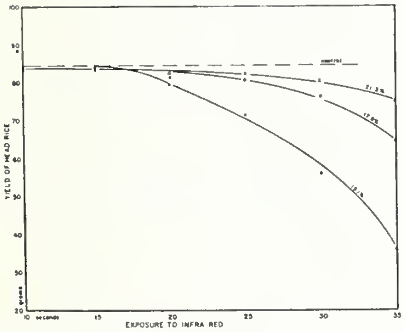

Figure 2. The effect of infra-red radiation on the yield of head rice from Nato rough rice in relation to the irradiation period and the initial moisture-content.

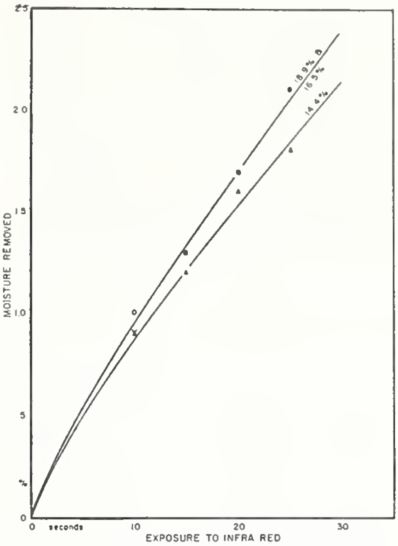

Figure 3. The relation between the per cent of moisture removed from Magnolia rough rice at three moisture-content levels and the infra-red irradiation period.

With 15 seconds irradiation the drying rate of Nato rice, but not of Magnolia was significantly correlated with initial moisture content. The correlations were highly significant for both varieties when the irradiation period was increased to 25 seconds.

The original difference in milling quality between the lot of Nato and the lot of Magnolia is shown by the milling yields of the controls (Tables 1 and 4). Magnolia controls averaged 2.5 grams less total milled rice and 9.3 grams less head rice than Nato. This inherent difference appears to be greater than any difference in head yield resulting from infra-red irradiation for a 15-second period (Fig. 5). A 25-second irradiation period however, shows distinct differences between the two varieties as shown by the regression coefficients for the relation between temperature and head yield (b Nato = —.146 and b Mag. = —1.283) and the relation between drying rate and head yield (b Nato =20.837 and b Mag. = 49.625).

Distinct basic differences in the effects of infra-red radiation between varieties are indicated by these data. Varietal differences do not appear to be related to grain type; however, it is essential that various lots of the same variety grown under different environmental conditions be studied to determine the limits of variation in reaction to infra-red drying for a given variety. If varietal differences can be conclusively established, infra-red drying of rice in the laboratory may become a useful procedure to characterize small samples of rice on the basis of their quality characteristics as well as their drying characteristics.

Acknowledgements

This work was done in cooperation with the Texas Agricultural Experiment Station.

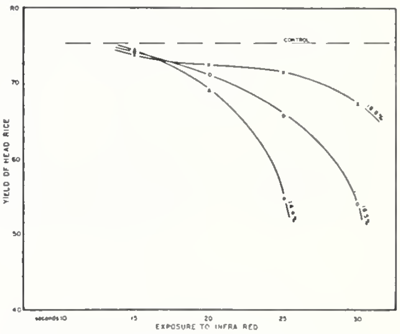

Figure 4. The effect of infra-red radiation on the yield of head rice from Magnolia rough rice in relation to the irradiation period and the initial moisture-content.

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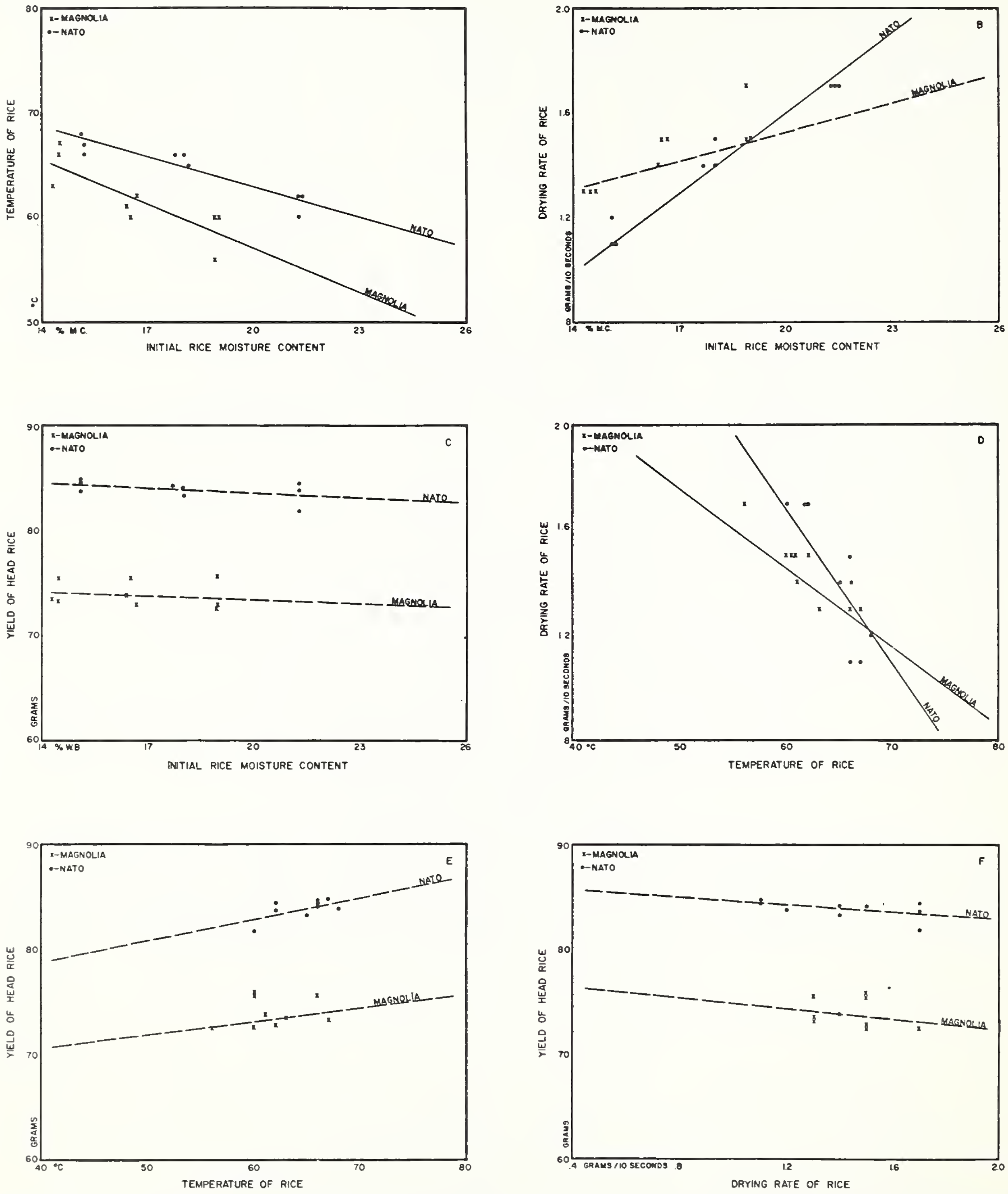

Figure 5. A comparison of the correlations between the rice moisture content, the temperature of the rice, the drying rate, and the yield of head rice for Nato and Magnolia rough rice irradiated for 15 seconds with infra-red. (A) Initial moisture-content and temperature, (B) Initial moisture-content and drying rate, (C) Initial moisture-content and yield of head rice, (D) Temperature and drying rate, (E) Temperature and yield of head rice and (F) Drying rate and yield of head rice. A broken line indicates a non-significant linear correlation.

The Effect Of Infrared Radiation On Immature Insects In Kernels Of Rough Rice

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The recent introduction of a ceramic panel gas-fired infrared heater, which produces infrared heat at a relatively low cost, has created considerable interest in the use of infrared heat for the drying of grain. Experiments conducted by Schroeder (1, 2), Schroeder and Rosberg (3), and Schroeder and Tilton (4) have demonstrated the possibility of drying rice by this method. They found that rough rice dried rapidly when subjected to temperatures of 122° to 158°F. in irradiation periods of 10 and 20 seconds, and this treatment did not lower the yield of head rice significantly. Since these temperatures in the range that may be lethal to insects, the possibility of controlling insects in rice by infrared drying was suggested.

Yeomans (5) concluded that the use of infrared radiation for the control of insects was not practical because of the expense, and because penetration by this wave length is poor. At that time the heat was produced by incandescent bulbs. Now, the cost of producing heat with the gas-fired ceramic-panel infrared heater is quite low.

Small laboratory tests were conducted at College Station and Houston, Tex., to determine the effects of infrared radiation on stored-rice insects that feed within the rice kernel. The rice weevil, **Sitophilus oryzae** (L.) and the lesser grain borer, **Rhyzopertha dominica** (F.) were selected for these experiments.

Century Patna rough rice containing 12.2 per cent moisture[2] was used in the first experiment. At the beginning of each week, for four weeks, approximately 2,500 grams of rice were infested with one-month-old adult rice weevils and lesser grain borers. Adult insects were removed from each sample at the end of a week; at the end of four weeks the four samples were combined and thoroughly mixed. The combined sample was then subdivided into 40 parts, each part containing 250 grams of infested rice. The infested samples were placed in pint Mason jars with filter paper covers until they were treated with infrared radiation.

The infested rice was placed in screened trays in layers about one kernel deep, and irradiated. A ceramic panel gas-fired infrared heater with a rated output of 48,000 BTU per hour was used. The intensity of the radiation was varied by increasing or decreasing the distance between the rice and the heater. A laboratory thermometer was placed at the level of the rice until a predetermined temperature was reached. This method gave only approximate temperatures of the rice. The tray was then removed from beneath the heater and the exposure time recorded. Samples were incubated at 86°F. and 60 per cent relative humidity. Adult insects were removed and counted five weeks after treatment.

The results indicate that irradiation of rough rice with infrared at intensities and exposures known to be harmless to the rice can be lethal to immature stages of rice weevils and lesser grain borers. There appeared to be a definite difference between the susceptibility of the two species to a given treatment; the lesser grain borer was more difficult to kill.

A different procedure was followed in the second experiment to yield more exact information. Century Patna rough rice containing 12.1 per cent moisture[3] was used. Rice was infested by the method described above, except that four lots were infested with rice weevils only, and four lots with lesser grain borers only. Forty 200-gram samples containing each species were treated. Trays with a surface area of one square foot were used in order to calculate the energy used in each treatment in irradiating a unit weight of rice. Radiation intensity and total energy input per treatment were calculated on the basis of the rated BTU output of the heater and the area irradiated at a given distance from the heater.

The rice was exposed for a predetermined time at three radiation intensities. The irradiation-time levels were calculated to give the same three levels of input energy per sample for each of the three intensity levels in order to study the effect of time of heating on the mortality rate of the insects. Immediately after irradiation each sample was weighed and returned to its container, and its temperature was determined by inserting a thermistor surface-temperature probe into the rice. The filter-paper covers were then replaced on the jars. Samples were selected at random for treatment, and each treatment was replicated four times. Replications were treated at different times. Four samples of each species of insect, not irradiated, served as controls. The adult insects were removed and counted at intervals throughout the period of emergence.

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[2] Determined by Tag-Heppenstall moisture meter.

[3] Determined by two-stage oven drying.

The distance between the rice and the heater was calculated to allow a ratio of approximately 1:2:3 for intensity, length of irradiation, and total energy input per sample. Equal temperatures of the rice were expected when equal amounts of energy per sample were expended; however, the data indicated clearly that the time factor, even for irradiation periods of less than a minute, influenced the final temperature.

The analyses of variance of total emergence of rice weevils and lesser grain borers showed the effect of treatments to be highly significant. All treatments reduced emergence by significant numbers. Emergence of the rice weevils was reduced 33 to 100 per cent, and emergence of the lesser grain borers was reduced 54 to 100 per cent.

The emergence data were analyzed to determine the significance of radiation intensity, energy input per sample, species differences, and data of emergence.

The total energy input per sample had a highly significant effect on emergence, which was significantly different at each of the three energy input levels. Emergence was inversely proportional to total energy input, indicating that insect mortality was primarily a function of the temperature to which the rice was heated. In this experiment rice weevils were completely controlled at rice temperatures averaging 133°F. and lesser grain borers at 154°.

The rate at which the temperature of the rice was increased appeared to be another factor in insect mortality. The data indicated that the more rapid the rise in temperature, the more insects were killed. This phase of the study needs further investigation; however, high radiation intensities were the most efficient in heating the rice to the desired temperatures under the conditions of these experiments.

Insect emergence was greatest 14 to 23 days after treatment, with another significant peak emergence period 30 to 37 days after treatment.

The interactions of date of emergence x species and the date of emergence x energy input per sample were also highly significant. It is apparent that the two species either reacted differently to treatment with infrared at certain stages of their life cycles or that disproportionate numbers of the various life stages of each species were present at the time of treatment.

The other significant interaction, date of emergence x total energy input, indicates a differential emergence on certain dates between different energy-input levels.

Conclusions cannot be drawn from the present data because the rate of infestation was three times greater for the lesser grain borer, and the relative prevalence of corresponding life stages was not known at the time of treatment.

These experiments indicated that rice weevils and lesser grain borers in rough rice can be controlled by irradiation with infrared. Using the gas-fired infrared heater for drying rough rice would have the additional benefit of killing all stages of these stored-rice insects in the rice during the drying process. Rough rice could then go into storage free of insects. It could be expected to remain in that condition with a minimum use of fumigants, provided that sources of infestation in and near the storage facilities were prevented from developing.

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